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THE EFFECTS OF PHOTOPERIOD AND TEMPERATURE ON THREE CROWNVETCH (*CORONILLA VARIA* L.) VARIETIES

A Thesis Presented

By

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INTRODUCTION

Crownvetch, (Coronilla varia L.), is a herbaceous perennial legume. It is characterized by coarse stems growing in a semi-erect manner and pinnate leaves that are oblong and blunt (3). It grows to approximately three feet in height, is densely rooted, and has flowers that are light pink to purple in color. Its rapidly spreading growth habit is due to aggressive lateral growth and natural reseeding.

Crownvetch has been proven to be a valuable soil stabilizer in Ohio and Pennsylvania (59, 65). Its most widely accepted use is for the prevention and control of soil erosion on areas adjacent to newly constructed highways and on deteriorating grass slopes near existing roadways (75, 70).

Crownvetch is now being used for roadside soil stabilization in Massachusetts. Its introduction into this state for this purpose has been primarily due to the investigations made by Zak and Kaskeski (98, 99, 100). Their investigations showed the relationship between crownvetch and soil pH, nurse crops, and time of seeding; however, little study has been made on the effects of light and temperature on early shoot and root growth of this legume. These environmental factors are quite variable throughout the growing season and affect the early growth of most plants. In order to establish crownvetch plants for erosion control and permanent roadside cover, it would be important to know the effects of the light and temperature interactions on growth of the crownvetch plant. A knowledge of the interrelationship of temperature and light on growth would also be beneficial for the practice of seeding and establishing crownvetch.

The purpose of this study was to evaluate the growth of three commercial varieties of crownvetch under various photoperiods and temperatures in growth chambers and in the field.

LITERATURE REVIEW

Crownvetch Description

Crownvetch, (*Coronilla varia* L.), is a herbaceous perennial legume. The genus is comprised of 20-30 species divided into three groups; annuals, brush-like perennials and herbaceous perennials (56). The word *Coronilla* denotes "little crown" (3) and is characteristic of crownvetch flowers which are approximately 1/2 inch long (3), circular (29), and are clustered together in dense umbels terminating axillary peduncles (29). Flower color ranges from light pink to purple depending upon the specific variety (39) and the age of the blossom. *Varia*, meaning variable, refers to the variation in flower color and growth habit of the species (75).

The mature plant is characterized by many coarse, hollow, herbaceous stems that may attain a length of five feet and have a semi-erect growth habit. Perpendicular to each main stem are compound leaves that are odd-pinnate with 11-25 leaflets that are smooth, oblong, blunt and sessile (29).

The root system is comprised of a small tap root and a dense, fibrous secondary root system. Some of the secondary roots are as thick as the primary root and are up to ten feet in length (42). They grow parallel to the soil surface and are from 3" to 9" beneath it. Most of the secondary root system is made up of thin root hairs of various lengths that may have oblong nodules attached. Vertical root growth may penetrate the soil to a depth of 3' to 5'.

Growth Characteristics

New growth on crownvetch is initiated each year from the over-wintered crown. Growth starts early in the spring and continues until the plant flowers and sets seed. It is a long-day plant and will flower from mid-June to late August (18, 56, 75). It has a high degree of drought tolerance which may be due in part to the extensive horizontal root system (26, 35, 42). This enables the plant to absorb enough water to produce a good seed set even though vegetative growth may have been checked earlier in the season by dry weather conditions (75).

Crownvetch reproduces sexually and asexually. Inbred lines can be obtained from the parent plant by removing the daughter plants that arise from adventitious buds located on the larger horizontal secondary roots.

Outbreeding results from the plants being openly pollinated by bees and other insects (2). This accounts for the large degree of phenotypic and genotypic variation among plants. The seed is encased in cylindrical, segmented pods approximately 1" to 2" long. Each segment is about 1/4" in length and usually contains one seed (75).

Very few of the seeds readily germinate because of a hard seed coat (10) and under normal conditions will not germinate until the following year. Once germinated the crownvetch seedlings are similar in appearance to red clover seedlings. This will last from 2 to 4 weeks depending on the growing conditions after which the crownvetch will take on its characteristic features.

Crownvetch is a winter-hardy plant (42, 75). An exception to this is seedlings that have germinated from September to November. These, because of their small size, will not be as hardy as mature plants and may be winter-killed (99). Crownvetch will remain green up until snowfall after which it becomes dormant and turns brown.

The natural habitat of crownvetch ranges throughout western and southern Europe, western Asia, and North Africa. It has been introduced into Belgium, Germany, the Netherlands, Poland, Portugal and Spain. In Switzerland it has been found at altitudes up to 5,248 feet (56). It is also common in Greece, Italy, Rumania, Russia and Syria (56).

History

The first arrival of crownvetch into this country was around 1905 when it was introduced as a contaminant in alfalfa seed imported from Europe. In 1935 Dr. Fred V. Grau, an extension agronomist from the Pennsylvania State University, noticed the crownvetch plants on a farm near Virginville, Pennsylvania and immediately recognized its potential as an erosion control plant (36). It was through the efforts of Dr. Grau that the first available crownvetch seed for research purposes was produced in 1947 (35).

Much of the earlier work with crownvetch was done with Pennsylvania ecotypes by the Department of Public Highways and the State University in Pennsylvania. Then as now its primary use was to prevent and/or control erosion on highway slope embankments. In addition to this, the plant is now being used for ornamental purposes on lake banks, in home gardens and around business and industrial complexes (42, 93). It is also being tested as a forage crop for sheep and cattle (16, 69).

Varieties

There are three commercial varieties of crownvetch available; they are Chemung, Emerald and Penngift.

The variety Chemung is a local ecotype that comes from a naturalized stand along the Chemung River in Big Flats, New York. It was released as a named variety by the Soil Conservation Service in 1961 (80).

The variety Emerald can be traced back to 1911 when the seed was collected in southeastern Russia and brought to this country (39). Its history from 1911 to 1937 is vague but in 1937 a bag of Emerald crownvetch seed was sent to the Iowa State College by the United States Department of Agriculture. Here the plant was grown and a suitable ecotype was selected by the Soil Conservation Service and the Iowa Agricultural Experiment Station. It was released as the variety Emerald in 1961 (56).

The variety Penngift was named and released by the Pennsylvania Agricultural Experiment Station in 1954, 19 years after it was "discovered" in this country. It is classified as a local ecotype but will adapt to environmental conditions similar to those in southeastern Pennsylvania (56).

There are many ecotypes, lines and strains of crownvetch that have been and are being tested, but only these three have been released as named varieties.

Some morphological differences exist among the three varieties. In the Emerald variety, seedling growth seems to be more vigorous (greater dry weight production, taller plants and larger leaves) (39, 47), whereas Penngift seedlings are the least vigorous (80). Work by Foote (30) conflicts with this; he indicates that Chemung is the best of the three varieties, while Sharp (80) says that Chemung is as vigorous in its growth as Emerald.

The three varieties can be distinguished from each other by the size of the cotyledons on young seedlings. McKee (58) measured the size of the cotyledons (length X width) of 5,008 plants and found that those of Chemung were the largest followed by Emerald and Penngift.

In comparing the varieties that are beyond the seedling stage, the order of greatest top growth production is Emerald, Chemung, and Penngift (30, 39, 47). In root production Emerald seems to produce the least dry weight according to the results reported by Foote (30). However, Langille (47) states that Emerald produced the most root dry weight. Both workers agree that Penngift has the lowest shoot/root ratio and those of Emerald and Chemung are about equal (30, 47).

The growth differences within a variety may be due to the fact that these varieties are not pure lines and as a result of crossbreeding exhibit heterozygosity in plant growth characteristics.

The varieties also differ in seed characteristics. The seed of Penngift weighs less than that of either Emerald or Chemung. Seed counts made by McKee (58) show that Penngift has 131,873 seeds/lb, Emerald 122,123 seeds/lb and Chemung 106,397 seeds/lb. There also seems to be a smaller percentage of brown and tan seeds in Penngift compared to the other two varieties. The normal seed color of all of the varieties is a dark mahogany red (56).

Legumes

Crownvetch is a legume belonging to one of the two most important plant families in agriculture, the Leguminosae (96). The other plant family of importance is the Gramineae. The word "legume" comes from the Latin word legere which means "to gather". This probably refers to the seed pods which were harvested by hand to prevent shattering and seed losses.

Various legumes have been cultivated before the time of Christ. Peas and beans were grown by the Lake Dwellers in Switzerland from 5000 to 4000 B.C. and soybeans by the Chinese between 3000 and 2000 B.C. (96). The Romans recognized the value of the legumes and introduced a crop rotation system using legumes as green manure crops (34).

There are many uses for both herbaceous and woody legumes. Some of these are: food for man, feed for both domestic and wild animals, timber, resins, tannins, gums, dyes, fiber, green manure and for erosion control (34).

Legumes, especially herbaceous legumes, are very effective in erosion control. They grow and spread rapidly and produce an abundance of top and root growth that aids in controlling erosion. The top growth acts as a mulch on the soil surface (34) and the root growth improves soil granulation thereby increasing soil water infiltration (13). The value of legumes such as birdsfoot trefoil (Lotus corniculatus L.), crownvetch (Coronilla varia L.), lespedeza (Lespedeza stipulaceae Maxim.) and the vetches when used to prevent and/or control soil erosion is well known (26, 34, 37, 70, 73, 75). In an experiment on a Shelby silt loam slope with an 8% decline Bennett (34) estimated that it would take 10 years to erode seven inches of the topsoil if the slope was left bare of vegetation, but it would take 4,580 years to erode seven inches of the topsoil if the slope had a cover crop of alfalfa on it.

Legumes and Soil Bacteria

Probably the most valuable characteristic of the legumes is that many of them are able to grow in soils of low fertility, soils such as those found on most cut and fill highway slopes and adjacent areas where only the subsoil exists. Legumes are able to grow in these areas because of a beneficial symbiotic relationship that the plant has with a rhizobial type of bacteria in the soil. According to Salisbury and Ross (78) the plant furnishes the bacteria with carbohydrate materials that are oxidized by the bacteria to obtain electrons needed by them to reduce atmospheric nitrogen to ammonia. According to Nicholas (61) the ammonia is then converted to glutamic acid. It may be in this or a related organic form that the nitrogenous compound moves out of the nodule and into the root tissue of the host plant where it is used in protein synthesis (52). It has been estimated that the bacteria in legumes can fix from 40 to 250 pounds of nitrogen per acre depending upon the species of legume grown (13, 28).

The bacteria are small, rod-shaped, single cells of the genus *Rhizobium* and can live in the soil for years if the environmental conditions of soil pH, moisture and temperature are favorable (28, 90). There are many strains of rhizobium and for the symbiotic relationship to be of maximum benefit to both plant and bacteria the legume has to be grown in association with the strain or strains that will not only infect the plant root hairs but also form nodules and fix atmospheric nitrogen.

The rhizobium will usually infect the legume root hairs at about the time the first true leaf appears (96). The infected root hairs may or may not be curled at the tip (68) where a hypha-like thread containing the bacteria grows from the point of entry on the root hair tip into the root cortex (64). Once in the cortical cells the rhizobium will multiply and as a result the infected cells and the adjacent ones will divide. As a result of this active cell division an outgrowth or nodule will form on the root with the rhizobium enclosed in it (96).

The nodules on annual cultivated legumes are usually large, fleshy and spherical, pyriform, clavate or flabellate in shape. They are found singly or in clusters near the tap root or on the first formed lateral roots. Nodules on perennials are small and elongated. They are usually clustered and widely distributed over the entire root system (96). The nodules are the site of nitrogen fixation by rhizobium. If the bacteria in the nodules are fixing nitrogen, the interior of the nodules will be of a pink or reddish coloration (61, 78). This is due to leghemoglobin, a hemoglobin type of compound (61), which may have an active role in the reduction of atmospheric nitrogen to ammonia (78).

The number of bacterial infections, nodule size and nodule number are all determined genetically by the plant host (74, 96), but are subject to modification by adverse environmental conditions such as high and/or low temperatures (4, 32, 43), low light intensity (41), inadequate photoperiod (41, 54, 82), and low soil pH (81).

One very important environmental factor affecting the growth of most legumes, including crownvetch, is soil acidity. If the soil pH is low (5.6 or less), crownvetch may not be able to become established (38, 75); if it does grow, it will do so very poorly (57, 98). This may be due to the fact that as soils become more acidic the availability of such nutrients as nitrogen, phosphorus, potassium, calcium and magnesium to the plant is reduced, whereas the availability of aluminum, iron and manganese increases and may become toxic (13). In moderately acidic soils Ruffner (76) observed that the crownvetch growth and establishment was only poor to fair while very dense stands were obtained on soils that were only slightly acidic or neutral (38, 57, 76, 98).

Since crownvetch is a legume and produces its own nitrogen in association with the soil rhizobium, a minimum of soil nitrogen is needed for establishment. In fact, an excess of nitrogen may cause an abundance of weed and grass growth and result in severe competition with the crownvetch. Hawk and Shrader (38), McKee (57) and Zak (98) have concluded that medium to high levels of both phosphorus and potassium in the soil are needed for good plant growth and establishment. Phosphorus is especially important during the young seedling stage of growth because it is used as an energy carrier (78) and as a constituent in the formation of nucleoproteins by the meristematic tissue (38, 52, 78).

Another soil factor that influences the growth of crownvetch is soil water drainage. The plant cannot tolerate excessively wet soil (38, 57). If grown under this condition the leaves will turn yellow in color and the root growth will be adversely affected (92).

Light

Energy in the form of solar radiation from cosmic rays up to visible light and infra-red radiation may have an effect on the growth of plants and animals. The portion of the electromagnetic spectrum that is most effective in having a quantitative influence on many plant processes is visible light which ranges from 390 to 760 millimicrons (78). Some of the plant processes and reactions that are influenced by light in the energy range are: photosynthesis, respiration, stomatal activity, transpiration, reproduction, direction of shoot growth and the size, shape and anatomy of leaves (72). Visible light varies in quality, intensity and duration.

The quality of light or color at different wavelengths affects various aspects of plant growth. Radiant energy in the 420 mμ (blue) and 660 mμ (red) range is the most efficient in photosynthesis (95, 97). Increase in leaf length is greater in red light than in green (52). Stem elongation is minimal in red light but increases as the wavelength increases from red to violet (400 mμ) (52, 97). Plant exposure to far-red light (700 mμ to 800 mμ) acts in some cases to reduce or inhibit such plant growth responses as floral initiation (9, 52), leaf expansion (48) and seed germination (52), whereas stem elongation is promoted by far-red light (51, 52).

Light Intensity and Plant Growth

Light intensity is the quantity of light that is incident upon a surface. Two ways in which light intensity can be expressed are in foot-candles (ft-c) or gram calories per square centimeter per minute (g cal/cm^2/min).

Some of the plant growth characteristics affected by light intensity are tillering (62), stem elongation (52, 94), leaf size and thickness (21, 94), number of stomates per leaf (21), total plant dry weight (20) and initiation of floral primordia (52).

Various levels of light intensity have an effect on the plant growth characteristics of legumes. As the light intensity increased from 25% to 100% sunlight, the number of stems produced per alfalfa plant also increased (22, 23); and in white clover (7) stem production increased when the light intensity was raised from 1000 ft-c to 2000 ft-c. As the light intensity increased the number of stems increased, but plant height was greater at a lower light intensity in alfalfa (22) and in crownvetch (47).

Total plant dry weight was found to be greater under high light intensity than low light intensity in experiments with alfalfa (22, 33, 63), birdsfoot trefoil (33), red clover (14, 33) and white clover (5). Crownvetch (47) root dry weight production was favored by 100% sunlight; shoot or top dry weight was greatest at 67% sunlight. The ratio of shoot growth to root growth decreased as the light intensity increased from 750 ft-c to 3000 ft-c on red clover and in crownvetch from 31% to 100% sunlight. This means that as the light intensity increases the top growth decreases and/or the root growth increases.

Light intensity also affects nodulation but in an indirect manner. Hopkins (41) found that shaded soybean plants had a lower fresh weight of nodules per plant than plants grown in full sunlight. He also noted that the shaded plant had a lower concentration of carbohydrates which may be due to a lower rate of photosynthesis. Since the rhizobium in the nodules utilizes carbohydrates in the plant for growth, a low carbohydrate concentration in the plant may have been the cause of poor nodule growth.

Photoperiod and Plant Growth

Duration of light or photoperiod is the number of hours that light is incident upon an object. Plants respond differently to various lengths of photoperiods and can be classified into many groups according to their response to flowering. According to Salisbury (77), Garner and Allard first proposed three classes of photoperiodic sensitive plants. These classes are long-day, short-day and day-neutral. Subsequent work with the interaction of photoperiod with the critical dark period and/or temperature has shown that there are many more classes of photoperiodic sensitive plants. The long-day and short-day are the most commonly studied groups (40).

A long-day plant is one that will flower if it is exposed to photoperiod equal to or greater than its critical photoperiod. The critical photoperiod is the minimum or maximum length of light in hours needed by a plant for flower initiation and development (40, 52). It is a relative value and may fluctuate with changes in light intensity and temperature (40). McCloud (53) has shown that some varieties of Ladino white clover, a long-day plant, will only flower in photoperiods that are at least 14 hours and 15 minutes in length.

A short-day plant is one that will flower in photoperiods that are shorter than its critical photoperiod. Lespedeza will only flower in photoperiods that are equal to or less than 13 hours and 30 minutes in duration (84). A day-neutral plant is one in which the length of the photoperiod has very little or no effect on flowering.

Crownvetch has been reported to be a long-day plant (18) but detailed information as to the magnitude of its critical photoperiod is lacking.

Long-day legumes that are grown under long-day conditions will exhibit characteristic responses in height (22, 46, 55), shoot and root dry weight production (17, 19, 54), nodulation (32, 41), and flowering (18, 44, 49).

The height of long-day legumes will usually be more erect if the plants are grown under day lengths greater than the critical photoperiod. This has been observed in alfalfa (18, 19, 22), birdsfoot trefoil (54, 55), crownvetch (18) and red clover (25, 46). The growth habit of the top growth of these legumes is tall and erect. When grown under short-day conditions the vegetation is flat or prostrate and closer to the soil surface (49, 54, 55, 63).

Although stem height is greatest under long photoperiods the number of stems per plant decreases under those light conditions (17, 18, 22, 25, 46).

A more accurate method of assessing the photoperiodic effects on plant growth is by dry weight determinations of the top and root growth.

Generally, in long-day legumes, such as alfalfa, birdsfoot trefoil, and crownvetch, the top growth production increases as the photoperiod increases (8, 17, 18, 19, 54), but root development and production may decrease (17, 18, 19, 44, 54). This results in an increased shoot/root ratio (more top growth than root growth) under long-day photoperiods (14, 54). Total plant production is greater under long-day photoperiods despite the fact that root production is less (14, 54).

Differences in photoperiod also affect nodulation. Hopkins (41) and Sironval (82) observed that photoperiods of 16 hours increased the nodule weight and number on soybean roots compared to little or no nodule formation in seven and eight hours of light. Nodule formation was retarded in subterranean clover (32) under 8-hour photoperiods but was normal in 12, 16 and 20 hours of light. McKee, working with bridsfoot trefoil (54), found that nodule size, weight, and mass was at a maximum in the natural photoperiod of 15 to 12 hours.

Photoperiod has its greatest effect upon the intensity of flowering of a long-day plant. Many investigators have found that increased flowering on biennial sweetclover (<u>Melilotus</u> <u>alba</u> Desr.) (44), alfalfa (18), red clover (15, 49), white clover (86), crownvetch (18), and reduced time to first flower in red clover (15, 49), have been associated with photoperiods equal to or greater than the critical photoperiods needed.

Light and Varieties

In some cases there are differences between varieties of the same species when subjected to various light treatments. Carlson (17) found significant differences between clones of alfalfa in adventitious stem site formation and shoot and root production when grown under (either) long- (16 hours) or short- (10-14 hours) day conditions. Coffindaffer (19) found no differences among three varieties of alfalfa or plant height or top growth production. Garza (31) also reported no differences between varieties of alfalfa in total plant dry weight when grown at 1000 ft-c and 4000 ft-c.

Using a total of seven different varieties of birdsfoot trefoil, Nittler (63) and McKee (54) observed differences between varieties in habit of growth, shoot and root weight, nodule number, mass and percent plants in flower at 8-, 9-, 11-, 13-, 15-, 24- and natural (15- to 12-) hour photoperiods.

Bula (14, 15), working with red clover, also found varietal differences in flowering. These differences were the percent of plants in flower and the length of time needed for 90% of the plants to flower.

Light and Temperature Interaction

The combined effects of light and temperature on plant growth can be quite different than the influence of either factor alone. Carlson (17) observed that adventitious stem site formation in alfalfa was at a maximum during short days (10 to 14 hours) at temperatures of 23.9°C/18.3°C but decreased as the temperature decreased to 18.3°C/10.0°C. Total plant dry weight was highest under the long-day photoperiod (16 hours) at 23.9°C/18.3°C followed by short-day conditions at the same temperatures. At temperatures of 18.3°C/10.0°C yields were low under both day length conditions.

The effect of the light and temperature interaction is also shown in the investigation by Schonhorst (79) who used ten different varieties of alfalfa. At 15.6° C and under 8- and 12-hour photoperiods plants of the ten varieties could be classified into three separate groups by plant height, each group statistically significant from the other. As the temperature was raised to 26.7°C the difference in plant height became less variable in the 8- and 12-hour photoperiods. As a result the three plant groups were distinct for plant height under the 16-hour photoperiod only.

To determine the effect of the light and temperature interaction on the total plant dry weight of alfalfa, Garza (31) used light intensities of 1000 ft-c and 4000 ft-c and temperatures of 15.0°C/15.0°C, 30.0°C/30.0°C and 30.0°C/15.0°C. The 4000 ft-c light intensity and 30.0°C/15.0°C temperature factors resulted in maximum production when observed separately and when combined. Gist and Mott (33), using light intensities of 200, 600 and 1200 ft-c and temperatures of 15.6°C, 21.1°C, 26.7°C and 32.2°C, observed that the total plant dry weight in alfalfa decreased as the light intensity went from 1200 ft-c to 200 ft-c. The dry weight also decreased as temperatures were increased from 15.6°C to 32.2°C in the 1200 ft-c and 200 ft-c treatments. An interaction effect was noted in the 600 ft-c treatment where the total plant dry weight increased as the temperature was increased from 15.6°C to 21.1°C.

Results by Beinhart (7) on the light and temperature interaction in white clover indicates that increased branching occurs on plants grown at high light intensity (2000 ft-c vs. 1000 ft-c) and at cool temperatures (18.3°C vs. 35.0°C). In another experiment, Beinhart (6) reported that high light intensity (2000 ft-c) and warm days and cool nights (30.0°C/17.0°C) resulted in maximum total leaf dry weight, leaf area and total plant production in white clover.

Nitrogen fixation (milligrams of nitrogen fixed per plant when grown in nitrogen-free culture) in barrel medic (Medicago tribuloides Desr.) and purple vetch (Vicia atropurpurea Desr.) (66) was maximum in plants grown under a light intensity of 800 ft-c and at 18.0°C and 24.0°C. Less nitrogen was fixed at the 400 ft-c treatment at all temperatures from 6.0°C to 30.0°C, but there were peaks at 18.0°C and 24.0°C.

The number of flowers produced in white clover is dependent upon both photoperiod and temperature (86). From light treatments of 10, 14 and 18 hours, only the 18-hour photoperiod produced maximum number of flowers at temperatures of 10.0°C and 30.0°C. The 14-hour photoperiod produced 71% and 80% as many flowers at those respective temperatures. At the growth temperature of 20.0°C the 14-hour photoperiod produced 121% as many flowers as the 18-hour photoperiod. This light and temperature interaction effect indicates that the optimum temperature and photoperiodic conditions for maximum flower production are approximately 25.0°C and 18 hours of light (86).

Under field conditions Kasperbauer (44) observed that fresh weight of biennial sweetclover roots and the number of buds per crown increased as the day length shortened and the mean temperature decreased. Foote (30) found that the total plant dry weight of five strains of crownvetch grown in a greenhouse increased approximately 300% during the long days and increasing temperatures between June 17, 1964 and July 30, 1964.

The present study investigates the effect of some of these light and temperature factors on the growth of three varieties of crownvetch. Results will be evaluated in terms of the use of this plant as an aid in controlling erosion on slope embankment along Massachusetts highways.

Temperature and Shoot Growth

There is relatively little published information pertaining to the effects of photoperiod and temperature on the growth of crownvetch. Many investigations have been conducted on other legumes, i.e., alfalfa (Medicago sativa L.), birdsfoot trefoil (Lotus corniculatus L.) and the clovers (Trifolium spp.), to relate these environmental factors to plant growth.

Temperature is one of the most important environmental factors influencing plant growth. It affects the processes of photosynthesis, absorption, assimilation, respiration, reproduction and almost every other process in the plant (72).

Different air temperatures have a varied effect on shoot growth as measured by plant height and dry matter production. Maximum plant height in alfalfa can be expected when the day/night air temperatures are neither too high (27.0°C/ 21.0°C) nor too low (23.9°C/15.6°C) (22, 87). Ueno et al. (87) and Smith (83) obtained the tallest plants at a day/night temperature of 27.0°C/21.0°C as compared to a high temperature of 32.0°C/27.0°C and a low of 21.0°C/15.0°C. Cowett (22), using vegetative cuttings of alfalfa, found that a slightly lower day/ night temperature of 23.9°C/15.6°C favored an increase in plant height while a high temperature of 32.2°C/23.9°C yielded shorter plants.

Crimson (*Trifolium incarnatum* L.), red (*Trifolium pratense* L.) and alsike (*Trifolium hybridum* L.) clover all exhibit maximum plant height at temperatures lower than the optimum for alfalfa. Crimson clover grows the tallest at 23.9°C/11.7°C (46) and red and alsike clover at 15.0°C/10.0°C (83).

Smith (83) working with birdsfoot trefoil, found that different air temperatures had no effect at all on the height of the plant.

There is no published data pertaining to the effect of temperature on the plant height of crownvetch, however, work has been done with the effects of temperature on cotyledon size. McKee (58) found that under day/night temperatures of 34.0°C/26.0°C the cotyledons of crownvetch seedlings 9 to 15 days old were 26% larger than those cotyledons grown at temperatures of 22.0°C/13.0°C. Similar work with white clover (*Trifolium repens* L.) indicates that lower temperatures (17.0°C/17.0°C or 23.0°C/23.0°C) are needed for maximum leaf size (6).

Maximum top growth production expressed as dry weight usually occurs at the same temperature needed for maximum plant height, as is reported in work with alfalfa (17, 22, 25, 87), alsike clover (83), red clover (33, 83) and white clover (6, 7). Exceptions to this were reported by Gist (33), Vough (91) and Nelson (60). They found that cooler air temperatures than those needed for optimum plant height produced the maximum top dry weight in alfalfa. Work with birdsfoot trefoil indicates that cool temperatures (21.1° C or less) are needed for maximum top growth production (33, 60, 83).

Possingham (67), in working with subterranean clover, used air temperatures of 20.0°C/15.0°C, 30.0°C/25.0°C and soil temperatures of 20.0°C and 30.0°C. Small differences in top growth were noted in plants grown at different air temperatures and at the same soil temperature. At both air temperatures top growth was reduced when the soil temperature was 30.0°C.

Temperature and Root Growth

The most important part of any plant used to control soil erosion is the root system. Plant roots holds the soil in place and protect it from the deleterious effects of excessive water runoff.

Most of the investigations on the effects of air temperature on legume roots have been done with alfalfa. Ueno (87), using seedlings of Cody and Vernal alfalfa, found that maximum root production occurred at 27.0°C/21.0°C as compared to 32.0°C/27.0°C and 21.0°C/15.0°C. Dermine (25) obtained similar results at 27.7°C/15.6°C. Maximum root production in Ranger alfalfa, red clover and birdsfoot trefoil seedlings was obtained by Gist and Mott (33) using a constant temperature of 15.6°C. The differences in temperature needed for maximum root production on alfalfa as reported by these workers may be due to the varieties used or the lighting conditions in each experiment. Ueno used 21,500 lux (2000 ft-c) for 18 hours and Gist used 12,912 lux (1200 ft-c) for 12 hours.

Temperature and Nodulation

Temperature has a direct effect on soil rhizobium and the nodulation of legumes. Although the rhizobium can live in the soil for years, high soil temperature of 50.0°C and higher (90) may be detrimental to the growth and survival of the bacteria in some low clay content soils. This was shown by Marshall with Rhizobium trifolii (50). The bacteria did not survive in a light soil at 70.0°C but did in a heavy textured soil at the same temperature. The optimum growth temperature for rhizobium is about 30.0°C but satisfactory growth and reproduction will occur at 17.0°C and 25.0°C (1).

The optimum temperature for rhizobium infection of the plant root hairs is lower than the optimum temperature for maximum growth of the bacteria. Barrios et al. (4) have shown that the optimum temperature for root hair infection in wax beans is 25.0°C. This agrees with work done by Pate (66) with barrel medic (Medicago tribuloides Desr.) and purple vetch (Vicia atropurpurea Desf.) and by Dart (24) with cowpeas (Vigna sinensis (L.) Endl.).

Optimum nodulation was recorded by Gibson (32) at 33.0°C in subterranean clover (Trifolium subterraneum L.) and by Dart (24) in cowpeas at the same temperature. However, both experiments involved secondary root nodulation and not primary root nodulation the maximum of which occurred at 25.0°C.

Nodule growth, weight and numbers in soybeans (Glycine max L. Merr.), red clover and field beans, was maximum at a soil temperature of 24.0°C (43). Possingham (67) recorded the largest number of nodules per subterranean clover plant at 30.0°C, however, the total amount of nitrogen in the plant was greater at 20.0°C.

Temperature and Flowering

An increase in air temperature usually hastened the time of flowering and increased the number of flowers per plant in alfalfa and red, white and alsike clover (71, 83, 86). This agrees with Britten (11, 12, 71) who showed that warm day and cool night temperatures were needed for increased flowering of white clover.

Temperature and Varieties

Some investigation have been done on the comparison of growth differences between varieties of the same species grown at different temperatures. Most of the work has been done with alfalfa because it is an important forage crop. Ueno (87) found that there were differences in flowering and dry weight production of leaves, stems and roots between three cultivars grown at 32.0°C/17.0°C, 27.0°C/21.0°C and 21.0°C/15.0°C. Blondon (8) also showed differences in total plant production of two different cultivars at 17.0°C/17.0°C, 24.0°C/24.0°C and 27.0°C/27.0°C. However, Garza (31) was unable to find any differences between two cultivars grown at 15.0°C/15.0°C, 30.0°C/30.0°C and 30.0°C/15.0°C. Schonhorst (79) was able to classify ten varieties of alfalfa into three distinct groups according to varietal differences in plant height at 15.6°C.

GROWTH CHAMBER STUDIES

A. Materials and Methods

1. Growth Chamber Factors. During 1970 and 1971 a series of experiments were conducted in growth chambers to determine the effect of photoperiod and temperature on the growth characteristics of three varieties of crownvetch, (*Coronilla varia* L.). Two Percival growth chambers, Model MB-60, were used in these experiments. Lighting in the chambers was supplied by twelve 48-inch cool-white inflorescent and eight 25 watt incandescent light bulbs to give a maximum of 5000 ft-c at the plastic light barrier. The duration of the light period or photoperiod was controlled by three 24-hour timers.

The temperature range of these chambers is from 4.4°C to 43.0°C, depending upon the lighting conditions. Each chamber was designed to provide a specific temperature to within ± 1.1°C of the desired manual setting. The temperature was regulated by thermostats which in turn were controlled by a fourth 24-hour timer.

2. Treatments. In this study, three photoperiods and three day/night temperatures were used to give a total of nine separate experiments. The photoperiods were of 9-, 12- and 15-hour duration. These photoperiods were similar to those used by Carlson (18), Ludwig (49), McKee (54, 55), Nittler (63) and Schonhorst (79), to obtain both short- and long-day growth effects with several long-day legumes (alfalfa, birdsfoot trefoil, crownvetch and red clover).

The three day/night air temperatures used were 23.9°C/18.3°C, 23.9°C/15.6°C and 23.9°C/12.8°C. These were chosen because of the success other workers (14, 17, 22, 45, 46) have had with some of these temperature combinations on the growth of long-day legumes. Air temperatures were measured with calibrated bimetallic dial thermometers with an accuracy of 1% of the scale range. Temperatures and relative humidity were recorded with a Bendix seven-day hygrothermograph, Model No. 176E.

The light intensity inside the chambers was maintained at a minimum of 2000 ft-c or 2.76 g/cal/cm^2/hr measured at plant height in pots near the edge of the shelf. It was maintained constant by either raising or lowering the shelf on which the pots rested or by replacing worn bulbs with new ones. The light intensity in the center of the shelf, at plant height, averaged 2366 ft-c or 3.26 g/cal/cm^2/hr. A minimum light intensity of 2000 ft-c was chosen because it was the highest practical limit that could be maintained and still have room for plant growth. Work by other investigators (5, 7, 14, 33, 63) has shown that 2000 ft-c or higher is adequate for satisfactory plant growth of long-day legumes. The light intensity was measured in foot-candles with a Weston Illumination Meter, Model No. 756.

The relative humidity in the chambers was kept high to avoid excessive water loss from the plants and soil. It fluctuated between 55% and 80% during the lighted hours and 70% and 95% during the dark periods.

The experimental design of this study was a 3 X 3 X 3 fixed factorial design. The pots in the chambers were randomized within two Latin squares of nine pots each. This was done to minimize the effects of an uneven distribution of light intensity within the chamber. All data was statistically analyzed by the Duncan New Multiple Range Test at the 5% level.

3. Plant Culture. Rhizobium inoculated seeds of the three crownvetch varieties (Chemung, Emerald and Penngift) were sown in three small plastic flats (one variety/flat) filled with a sterilized peat/soil mixture. They were put into a growth chamber for approximately 21 days or until the second set of true leaves began to unfold. At this stage of growth, seedlings of uniform height from each variety were selected, transplanted into 6-inch plastic flower pots and then put into a growth chamber and grown for 60 days. Six seedlings from each of the three varieties were transplanted (one seedling/variety/pot) for a total of 18 potted plants per experiment.

4. Soil Mixture. The soil mix in the flats and pots was 25% peat moss (by volume) that had been sifted through a 12/64-inch mesh screen and 75% soil obtained from the University of Massachusetts farm in South Deerfield, Mass. A mechanical analysis of the field soil showed it to be a silt loam composed of 38.6% sand, 50.4% silt and 11.0% clay. The pH of the field soil was 6.5 and required no liming for adequate growth of crownvetch according to results obtained by other workers (38, 57, 76). Nutrient analysis (Ca, K, P, Mg and NO_3) of the soil indicated it to be of high fertility. One and one half to two ounces of rhizobium (*Coronilla varia* L.) was added to the peat/soil

mixture during mixing. Each 6-inch pot contained 3.5 pounds of the air-dried peat/soil mixture. The soil was not sterilized.

After transplanting, the crownvetch seedlings were watered, but it was found that when plants were watered to the field capacity of the soil, the soil dried out too rapidly and when they were watered to the pot capacity, a saturated soil condition resulted. A compromise between these two extremes was obtained by adding enough water (475 cc) to each pot to bring the soil to 3/4 of the pot capacity. Plants were watered in this manner (3/4 pot capacity) throughout the growing period whenever the soil moisture decreased to 50% of the field capacity which was determined by weighing the pots. This watering procedure was used for the first two experiments only. In subsequent experiments the plants were watered to 3/4 of the pot capacity immediately after the seedlings were transplanted and thereafter only when visual observation of the soil indicated that it was near the 50% field capacity value that was determined in the first two experiments.

5. Observation Procedures. At the end of each experiment the pots were removed from the growth chamber and measurements were made on shoot height, root length, number of nodules per plant, and shoot and root dry weights. From the dry weight data the shoot/root ratio was calculated.

Plant height was measured in centimeters from the crown of the plant to the tip of the tallest stem. The top growth was then cut at the crown, put into labeled paper bags, and then dried in an oven at 95.0°F to 115.0°F for three to five days. To soften the soil and minimize root damage during washing, the roots with soil intact were taken out of the pots and placed in trays of water for

12 to 15 hours. The washed roots were measured in centimeters from the crown to the root tip. Pink nodules on the roots of each plant were counted. The roots were then dried for the same length of time and temperature as the shoots. When the shoots and roots were brittle dry, they were weighed on a Mettler gram scale.

B. Results

Photoperiod

Shoot Height. All varieties of crownvetch grown in the 15-hour photoperiod exhibited long-day growth responses of increased plant height and an erect growth habit. These plants were approximately 2.5 times the height of those grown at either the 9- or 12-hour photoperiod. This difference in plant height was highly significant statistically (Table 1 and Figure 1).

The shorter photoperiods of 9 and 12 hours produced plants that had a semi-prostrate growth habit with dense foliage. There was no difference statistically in plant height between all plants grown at these two photoperiods (Figures 2, 3 and 4).

At the 15-hour photoperiod the varieties Penngift and Chemung produced the tallest plants while Emerald was significantly shorter. In the 9- and 12-hour photoperiods Penngift produced the shortest plants, but these were not significantly different from the other varieties at those two photoperiods (Table 2 and Figure 5A).

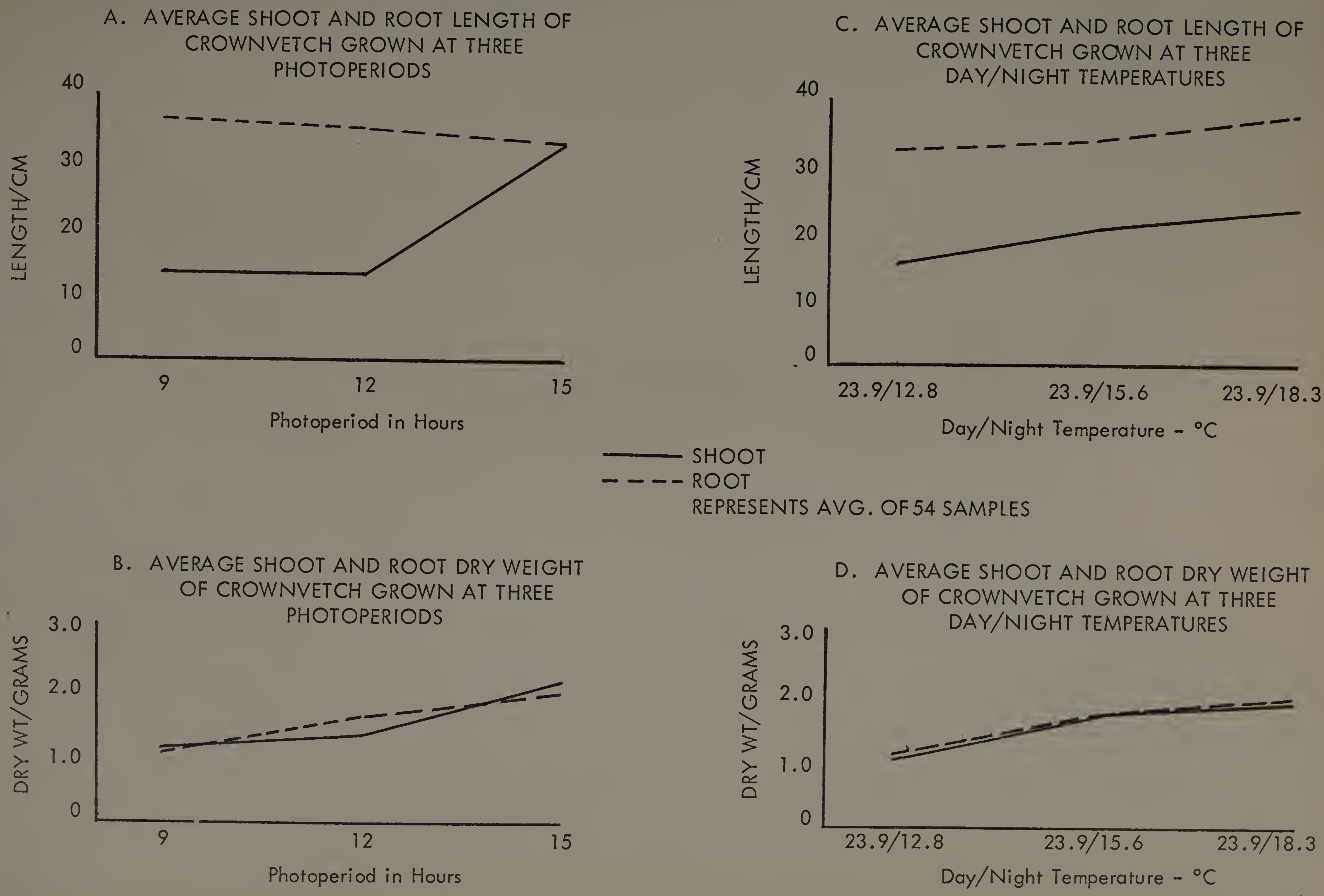
TABLE 1

PHOTOPERIODIC AND TEMPERATURE EFFECTS ON THE SHOOT AND ROOT LENGTHS AND DRY WEIGHTS OF CROWNVETCH GROWN FOR 60 DAYS

Photoperiod		Length	Dry wt	Temperature		Length	Dry wt
hr		cm	g			cm	g
9	Shoot	13.72 a [x]	1.12 a	23.9°C/12.8°C	Shoot	15.59 a	1.06 a
	Root	36.37 a	1.11 a		Root	32.87 a	1.09 a
12	Shoot	13.38 a	1.35 b	23.9°C/15.6°C	Shoot	20.65 b	1.70 b
	Root	35.30 a	1.58 b		Root	34.20 a	1.65 b
15	Shoot	32.81 b	2.17 c	23.9°C/18.3°C	Shoot	23.68 c	1.88 c
	Root	33.39 a	2.01 c		Root	37.98 b	1.95 c

[x] Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

FIGURE 1



A. AVERAGE SHOOT AND ROOT LENGTH OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
LENGTH/CM
40
30
20
10
0
9
12
15
Photoperiod in Hours
C. AVERAGE SHOOT AND ROOT LENGTH OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
LENGTH/CM
40
30
20
10
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C
SHOOT
ROOT
REPRESENTS AVG. OF 54 SAMPLES
B. AVERAGE SHOOT AND ROOT DRY WEIGHT OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
DRY WT/GRAMS
3.0
2.0
1.0
0
9
12
15
Photoperiod in Hours
D. AVERAGE SHOOT AND ROOT DRY WEIGHT OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
DRY WT/GRAMS
3.0
2.0
1.0
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C

FIGURE 2. CROWNVETCH GROWTH AFTER 60 DAYS IN A 9-HOUR PHOTOPERIOD AT 23.9°C/18.3°C.

FIGURE 3. CROWNVETCH GROWTH AFTER 60 DAYS IN A 12-HOUR PHOTOPERIOD AT 23.9°C/18.3°C.

FIGURE 4. CROWNVETCH GROWTH AFTER 60 DAYS IN A 15-HOUR PHOTOPERIOD AT 23.9°C/18.3°C.

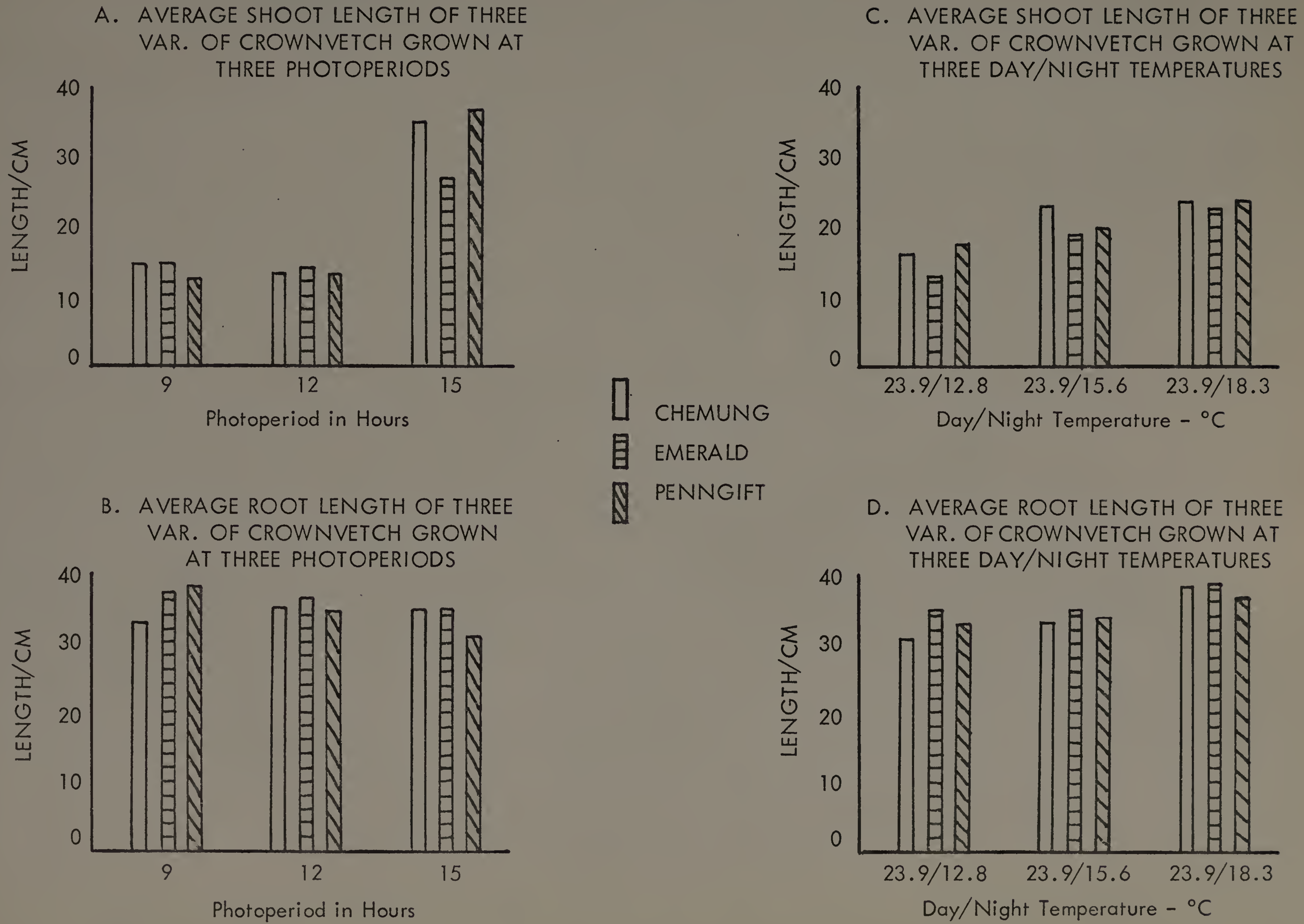
TABLE 2

AVERAGE SHOOT AND ROOT LENGTH IN CM OF CHEMUNG, EMERALD, AND PENNGIFT CROWNVETCH GROWN AT THREE PHOTOPERIODS FOR 60 DAYS

Variety	PHOTOPERIOD					
	9-Hour		12-Hour		15-Hour	
	Shoot	Root	Shoot	Root	Shoot	Root
Chemung	14.4 a x/	33.4 ab	13.3 a	34.9 ab	34.8 c	34.6 ab
Emerald	14.4 a	37.6 ab	14.0 a	36.4 ab	26.7 b	34.8 ab
Penngift	12.3 a	38.2 b	12.8 a	34.6 ab	36.9 c	30.8 a

x/ Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

FIGURE 5


A. AVERAGE SHOOT LENGTH OF THREE VAR. OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
LENGTH/CM
40
30
20
10
0
9
12
15
Photoperiod in Hours
B. AVERAGE ROOT LENGTH OF THREE VAR. OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
LENGTH/CM
40
30
20
10
0
9
12
15
Photoperiod in Hours
CHEMUNG
EMERALD
PENNGIFT
C. AVERAGE SHOOT LENGTH OF THREE VAR. OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
LENGTH/CM
40
30
20
10
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C
D. AVERAGE ROOT LENGTH OF THREE VAR. OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
LENGTH/CM
40
30
20
10
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C

Root Length. The average root length of all three varieties was the shortest for plants grown at the 15-hour photoperiod and the longest in the 9-hour photoperiod. The differences in root length for the three photoperiods were small, however, and were not statistically significant (Table 1 and Figure 1 A).

With the exception of the difference in root length of Penngift grown in the 9- and 15-hour photoperiods, there were no significant differences in the length of the roots of all varieties as affected by the three photoperiods (Table 2 and Figure 5 B).

Shoot and Root Dry Matter Production. The dry weight production of shoots and roots of crownvetch increased as the length of the three photoperiods increased (9, 12 and 15 hours). The highest yields were obtained at the 15-hour photoperiod and were almost twice those obtained at the 9-hour photoperiod. The dry matter production of both shoots and roots was significantly different between each photoperiod (Table 1 and Figure 1 B).

Chemung produced the greatest shoot weight in the 15-hour photoperiod. Emerald, however, was the most productive at the 9- and 12-hour photoperiods, and also produced the most root weight in all three photoperiods. At the photoperiods in which Emerald was most productive, the shoot and root yields of Chemung and Penngift were approximately the same (Table 4 and Figures 6 A, 6 B).

Nodule Number. The number of nodules on crownvetch roots grown in the three photoperiods (9, 12 and 15 hours) averaged 83, 94, and 106 nodules per plant, respectively. Plants grown in the 15-hour photoperiod had the greatest number of nodules per plant and were significantly higher in nodule production than from plants in the 9-hour photoperiod.

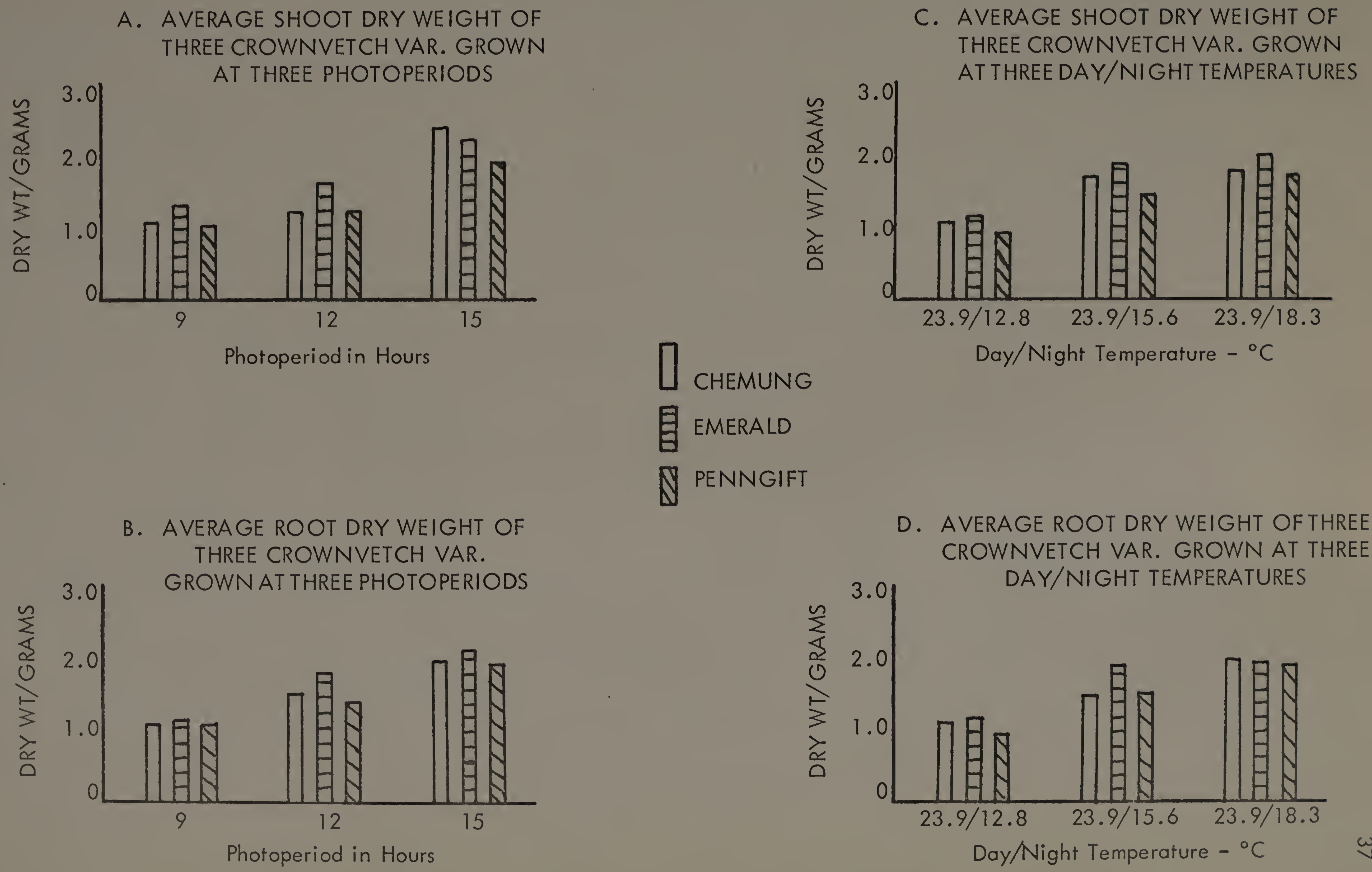
TABLE 4

AVERAGE SHOOT AND ROOT DRY WEIGHT IN GRAMS OF CHEMUNG, EMERALD, AND PENNGIFT CROWNVETCH GROWN AT THREE PHOTOPERIODS FOR 60 DAYS

	PHOTOPERIOD					
Variety	9-Hour		12-Hour		15-Hour	
	Shoot	Root	Shoot	Root	Shoot	Root
Chemung	1.06 a x/	1.07 a	1.22 ab	1.54 bde	2.39 e	1.97 de
Emerald	1.27 ab	1.15 ab	1.60 bc	1.80 cde	2.22 de	2.12 e
Penngift	1.03 a	1.11 ab	1.23 ab	1.39 abc	1.91 cd	1.94 de

x/ Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

FIGURE 6


A. AVERAGE SHOOT DRY WEIGHT OF THREE CROWNVETCH VAR. GROWN AT THREE PHOTOPERIODS
B. AVERAGE ROOT DRY WEIGHT OF THREE CROWNVETCH VAR. GROWN AT THREE PHOTOPERIODS
C. AVERAGE SHOOT DRY WEIGHT OF THREE CROWNVETCH VAR. GROWN AT THREE DAY/NIGHT TEMPERATURES
D. AVERAGE ROOT DRY WEIGHT OF THREE CROWNVETCH VAR. GROWN AT THREE DAY/NIGHT TEMPERATURES
DRY WT/GRAMS
3.0
2.0
1.0
0
9
12
15
Photoperiod in Hours
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C
CHEMUNG
EMERALD
PENNGIFT

There were no statistical differences in nodule production between varieties exposed to the 9- and 15-hour photoperiods. The only significant difference was between Emerald and Penngift in the 12-hour photoperiods. Emerald averaged 116 nodules per plant compared to Penngift's 72 (Table 6 and Figure 7 B).

Shoot/Root Ratio. The shoot/root ratio of crownvetch was the lowest at the 12-hour photoperiod (.85) and highest at the 15 (1.08). There were small differences in the shoot/root ratio between varieties grown in the three photoperiods. These differences did not appear to establish any particular pattern (Table 6 and Figure 7 A).

Temperature Effect

Shoot Height. The shoot height of crownvetch increased as the night temperatures increased from 12.8° C to 18.3° C. The average plant height of all varieties grown at 23.9° C/12.8° C, 23.9° C/15.6° C and 23.9° C/18.3° C was 15.6 cm, 20.7 cm and 23.7 cm, respectively, and was significantly different at the 5% level for each day/night temperature (Table 1 and Figure 1 C).

Root Length. The length of crownvetch roots increased as the night temperatures were increased; greatest length being obtained at 18.3° C. There was a statistical difference in root length for plants grown at 18.3° C and two lower temperatures but not between the two lowest day/night temperature regimes (Table 1 and Figure 1 C).

There were no significant differences in root length between varieties at any temperature. Emerald seemed to be a little more vigorous in root growth than the other two varieties in that it produced slightly longer roots at all temperatures (Table 3 and Figure 5 D).

TABLE 6

AVERAGE SHOOT/ROOT RATIO AND NODULE NUMBER PER PLANT OF CHEMUNG, EMERALD AND PENNGIFT CROWNVETCH GROWN AT THREE PHOTOPERIODS FOR 60 DAYS

Variety	PHOTOPERIOD					
	9-Hour		12-Hour		15-Hour	
	S/R	Nodules	S/R	Nodules	S/R	Nodules
Chemung	.99	85.11 ab x/	.79	94.44 abc	1.21	110.00 bc
Emerald	1.10	90.28 abc	.89	115.56 c	1.05	113.33 c
Penngift	.93	75.28 a	.88	72.22 a	.98	93.33 abc
$\bar{x}$	1.01	83.56	.85	94.07	1.08	105.55

x/ Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

$\bar{x}$ Mean of the three varieties.

FIGURE 7

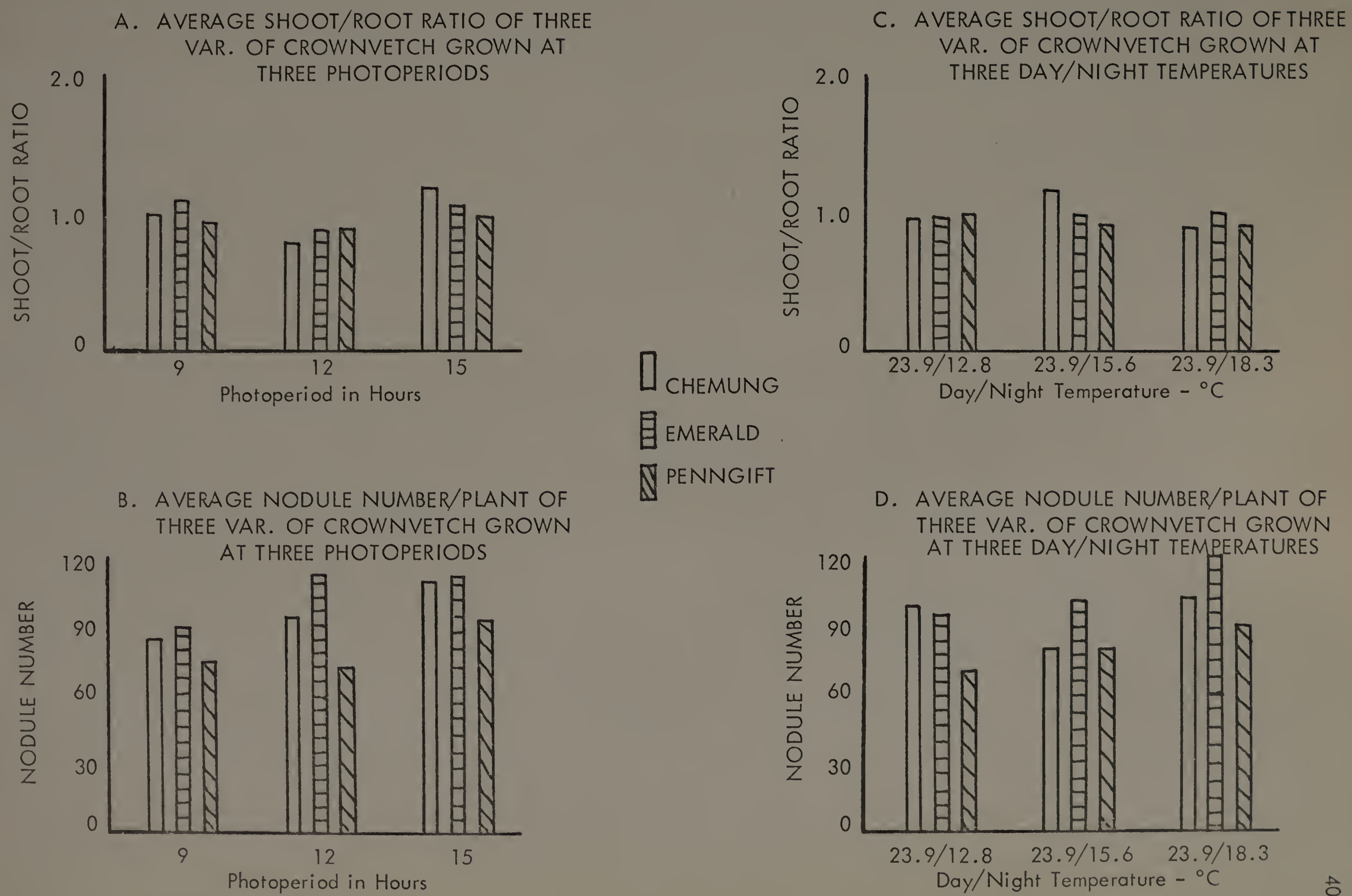

A. AVERAGE SHOOT/ROOT RATIO OF THREE VAR. OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
SHOOT/ROOT RATIO
2.0
1.0
0
9
12
15
Photoperiod in Hours
C. AVERAGE SHOOT/ROOT RATIO OF THREE VAR. OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
SHOOT/ROOT RATIO
2.0
1.0
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C
CHEMUNG
EMERALD
PENNGIFT
B. AVERAGE NODULE NUMBER/PLANT OF THREE VAR. OF CROWNVETCH GROWN AT THREE PHOTOPERIODS
NODULE NUMBER
120
90
60
30
0
9
12
15
Photoperiod in Hours
D. AVERAGE NODULE NUMBER/PLANT OF THREE VAR. OF CROWNVETCH GROWN AT THREE DAY/NIGHT TEMPERATURES
NODULE NUMBER
120
90
60
30
0
23.9/12.8
23.9/15.6
23.9/18.3
Day/Night Temperature - °C

TABLE 3

AVERAGE SHOOT AND ROOT LENGTH IN CM OF CHEMUNG, EMERALD, AND PENNGIFT CROWNVETCH GROWN AT THREE TEMPERATURES FOR 60 DAYS

	TEMPERATURE					
Variety	23.9°C/12.8°C		23.9°C/15.6°C		23.9°C/18.3°C	
	Shoot	Root	Shoot	Root	Shoot	Root
Chemung	16.0 ab[x]	30.9 a	22.7 b	33.6 ab	23.8 b	38.4 b
Emerald	13.0 a	34.9 ab	19.3 ab	34.8 ab	22.8 b	39.0 b
Penngift	17.7 ab	32.8 ab	19.9 ab	34.2 ab	24.1 b	36.6 ab

[x] Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

Shoot and Root Dry Weight Production. Increasing the day/night air temperatures resulted in significant increases in the shoot and root dry matter production of crownvetch. Plants grown at the highest night temperature (18.3°C) produced the maximum shoot and root weight while those plants growing at the lowest night temperature (12.8°C) produced the lowest yields (Table 1 and Figure 1 D).

The differences in shoot weight between varieties were not statistically significant for plants grown at each temperature (Table 1 and Figure 6 C). Root production (dry weight) of Emerald and Chemung was significantly different at 15.6°C, Emerald average 1.93 grams per plant as compared to 1.46 grams for Chemung (Table 5 and Figure 6 D).

Nodule Number. The number of nodules (88.8 and 86.4 respectively) per plant was approximately the same for plants grown in the temperature regimes of 12.8°C and 15.6°C. The number of nodules (108.0) on plants grown at 18.3°C was significantly greater than those of plants grown at the two other growth temperatures (Table 7).

Chemung produced the largest number of nodules per plant at 12.8°C while Emerald produced more at 15.6°C and 18.3°C. Penngift produced the least number of nodules per plant at all temperatures (Table 7 and Figure 7 D).

Shoot/Root Ratio. As the night air temperature went from 12.8°C to 15.6°C the shoot/root ratio increased from .97 to 1.03 and then decreased to .96 at 18.3°C.

TABLE 5

AVERAGE SHOOT AND ROOT DRY WEIGHT IN GRAMS OF CHEMUNG, EMERALD, AND PENNGIFT CROWNVETCH GROWN AT THREE TEMPERATURES FOR 60 DAYS

Variety	TEMPERATURE					
	23.9°C/12.8°C		23.9°C/15.6°C		23.9°C/18.3°C	
	Shoot	Root	Shoot	Root	Shoot	Root
Chemung	1.08 ab[x]	1.14 ab	1.73 cd	1.46 b	1.82 cd	1.97 c
Emerald	1.15 ab	1.18 ab	1.91 cd	1.93 c	2.02 d	1.96 c
Penngift	0.94 a	0.94 a	1.45 bc	1.57 bc	1.77 cd	1.92 c

[x] Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

TABLE 7

AVERAGE SHOOT/ROOT RATIO AND NODULE NUMBER PER PLANT OF CHEMUNG, EMERALD AND PENNGIFT CROWNVETCH GROWN AT THREE TEMPERATURES FOR 60 DAYS

	TEMPERATURE					
Variety	23.9°C/12.8°C		23.9°C/15.6°C		23.9°C/18.3°C	
	S/R	Nodules	S/R	Nodules	S/R	Nodules
Chemung	.95	99.44 bcd[x/]	1.18	79.00 ab	.92	111.11 cd
Emerald	.97	95.83 abc	.99	101.11 bcd	1.03	122.22 d
Penngift	1.00	71.11 a	.92	79.17 ab	.92	90.56 abc
$\bar{x}$	.97	88.79	1.03	86.43	.96	107.96

[x/] Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

$\bar{x}$ Mean of the three varieties.

There were small differences in the shoot/root ratio between varieties at 12.8°C and 18.3°C but at 15.6°C the shoot/root ratio for Chemung was larger (1.18) than those of either Emerald (.99) or Penngift (.92) (Table 7 and Figure 7C).

Light and Temperature Interaction

Shoot Height. An increase in the night air temperature and/or an increase in the duration of the photoperiod resulted in greater shoot height of all varieties of crownvetch. Two exceptions were in the 9-hour photoperiod at temperatures of 15.6°C and 18.3°C (Table 8). Under these conditions crownvetch plants were slightly taller than those grown in the same temperatures at the 12-hour photoperiod but were not statistically different.

Root Length. Root length also increased as night temperatures were elevated and decreased as the photoperiod was lengthened (Table 8). A reversal of this was found in plants grown in the 9-hour photoperiod at 15.6°C. The average root length of these plants was the lowest for all photoperiods at 15.6°C and for all temperatures.

Shoot and Root Dry Matter Production. With the exception of a very slight decrease in shoot and root dry weight production in plants grown in the 12-hour photoperiod at 18.3°C, the average shoot and root dry weight of all crownvetch varieties increased as the length of the photoperiod and the night temperatures were increased (Table 8).

Nodule Number. The number of nodules produced by plants grown at each temperature and photoperiod interaction was quite large. Plants grown in the 15-hour photoperiod at 18.3°C and 15.6°C and in the 12-hour photoperiod at 18.3°C had the largest number of nodules (Table 8).

TABLE 8

THE EFFECTS OF PHOTOPERIOD AND TEMPERATURE ON THE GROWTH OF CROWNVETCH GROWN FOR 60 DAYS

Plant Growth Characteristics	PHOTOPERIOD 9-Hour	12-Hour	15-Hour
	Day/Night Temperature - 23.9°C/12.8°C		
Shoot ht, cm	10.56 a x/	10.83 a y/	25.39 b
Root length, cm	35.78 abc	33.49 ab	29.29 a
Shoot dry wt, g	0.85 a	0.94 ab	1.39 c
Root dry wt, g	.85 a	1.15 ab	1.28 b
Shoot/root ratio	1.00	.86	1.09
Nodule number	103.61 cd	88.89 bc	73.89 ab
	Day/Night Temperature - 23.9°C/15.6°C		
Shoot ht, cm	14.72 a	13.67 a	33.56 c
Root length, cm	33.06 ab	35.44 abc	34.11 abc
Shoot dry wt, g	1.24 bc	1.56 c	2.29 d
Root dry wt, g	1.08 ab	1.89 d	2.00 d
Shoot/root ratio	1.15	.83	1.15
Nodule number	62.61 a	75.28 ab	121.39 d
	Day/Night Temperature - 23.9°C/18.3°C		
Shoot ht, cm	15.89 a	15.67 a	39.50 d
Root length, cm	40.28 c	37.00 bc	36.67 bc
Shoot dry wt, g	1.27 c	1.54 c	2.83 e
Root dry wt, g	1.40 bc	1.70 cd	2.75 e
Shoot/root ratio	.91	.91	1.03
Nodule number	84.44 abc	118.06 d	121.39 d

x/ Average of 18 replications.

y/ Means of the same growth effect followed by letters in common are not statistically significant at the 5% level according to Duncan's New Multiple Range Test.

Shoot/Root Ratio. Although the lowest shoot/root ratios were obtained in the 12-hour photoperiod at temperatures of 12.8°C and 15.6°C and at 18.3°C in the 9- and 12-hour photoperiods (Table 8), there was no particular trend between the shoot/root ratio and light and temperature.

C. Discussion

Effect of Photoperiod on the Growth of Crownvetch

Crownvetch grown at a long photoperiod of 15 hours produced plants that accumulated more shoot and root dry matter, were taller and had more nodules than those plants grown at the 9- or 12-hour photoperiods. This increase in top growth (shoot height and weight) of the plant should result in greater efficiency in controlling raindrop erosion and in reducing the velocity of water runoff (27).

The decrease in root length of plants grown at increasing photoperiods (9, 12 and 15 hours) was not statistically significant and is of no practical importance.

The significant increase in shoot and root dry matter production of plants grown at the 15-hour photoperiod as compared to those grown at the other photoperiods indicates that crownvetch has a definite photoperiodic response that can be correlated to the duration of the light period incident upon the plant. Plants in these experiments did not flower because of the short growing period, therefore, it is difficult to ascertain what the critical photoperiod might be. However, the increase in shoot height and shoot and root dry matter production shows that this legume responded like many other long-day legumes when grown in long-day photoperiods. These observations are similar to those made by many investigators (8, 17, 18, 19, 22, 44, 46, 54, 55). From these observations one can postulate that crownvetch grown in decreasing photoperiods (as those occurring naturally in the fall) will not grow as profusely as those planted in the spring (increasing natural photoperiods).

The fact that Chemung and Emerald produced a greater amount of shoot and root growth than did Penngift should be considered when selecting a specific variety for use in erosion control.

The number of nodules on crownvetch roots increased at each successively longer photoperiod. This increase in nodule number as affected by photoperiod has also been reported by Gibson (32), McKee (54) and Sironval and Bonnier (82) working with other long-day legumes. The reason for this increase in nodules may be due to the greater shoot and root production at the longer photoperiods. An increasing root system would provide more root hairs or sites for possible rhizobial infection and a greater volume of top growth could manufacture more carbohydrates, part of which would be used by the rhizobium for continued growth and reproduction.

The fact that Emerald produced more nodules per plant than the other varieties is important. Crownvetch is normally planted on slopes which are composed of soil of low fertility. The ability of a specific variety to produce more nodules, and possibly more nitrogen, would undoubtedly be beneficial to that variety in maintaining itself in low fertility soils.

The reason for the low shoot root ratio for plants grown in the 12-hour photoperiod is difficult to explain but may be due to a high percentage of root dry weight, 53.7% (% of total plant dry weight) as compared to plant root weight in the 9- and 15-hour photoperiods (49.8% and 48.1%, respectively). The cause of this high percentage of root growth in the 12-hour photoperiod is not known.

Effect of Temperature on the Growth of Crownvetch

Plants grown at the highest day/night air temperature (23.9°C/18.3°C) produced the greatest shoot and root length and more dry matter production than plants grown in the two lower temperature regimes. The data indicates that the yields of these growth characteristics still appeared to be increasing at 18.3°C. It is possible that the night temperatures used were not of the magnitude required by the plants to produce optimum growth. The optimum growth of crownvetch (as affected by night air temperatures) would appear to occur at temperatures higher than 18.3°C.

The highest night temperature (18.3°C) was the most beneficial for maximum nodule production on all varieties of crownvetch roots. This agrees, in part, with results obtained by Barrios et al (4), Dart and Mercer (24) and Pate (66) who observed that nodule numbers increased to a maximum at 25.0°C.

Because of the inconsistency in the shoot/root ratios there is no indication of any type of trend in the ratio for all plants grown at the three day/night air temperatures or between varieties grown at these temperatures.

Although Emerald had the shortest plants at all temperatures, it produced more shoot and root weight and more nodules than the other varieties (with the exception of being second to Chemung in root production at 18.3°C).

Because crownvetch produced greater top and root growth (length and dry weight) and more nodules at higher temperatures, it would seem reasonable to assume that crownvetch, specifically the variety Emerald, would be most effective as an erosion control aid on warmer (southerly facing) roadside slopes in the New England area.

Effect of Light and Temperature Interaction

An increase in the magnitude of the environmental growth factors of photoperiod and temperature usually caused an additive effect on shoot height and shoot and root dry matter production.

There were two exceptions to this increase in growth for shoot production, the first being in the 9-hour photoperiod at 23.9°C/18.3°C and the second in the 12-hour photoperiod at the same temperature. In each case shoot dry matter production of plants grown at these conditions was about the same as or less than those plants grown at 23.9°C/15.6°C in each photoperiod mentioned. Shoot production in the 15-hour photoperiod at 18.3°C was significantly greater than at 15.6°C (Table 8). This indicates that, at the shorter photoperiods, night temperatures greater than 15.6°C only result in a minimal effect on shoot dry matter production. This may be attributed to the short photoperiods which limit shoot growth. This limiting effect of photoperiod is absent at the 15-hour photoperiod as shown by the increased shoot yields at each successively higher temperature.

No explanation can be given for the decrease in root length for plants grown at 9 hours and 15.6° C. Although there were no definite trends in nodule number between varieties grown at each temperature and photoperiod, it was noticed that more nodules were found on plants grown in the longer photoperiods and at the higher night temperatures.

FIELD STUDY

A. Materials and Methods

1. Plant Culture. The seasonal effects of light and temperature on some of the growth characteristics of the three crownvetch varieties were evaluated during the 1969 growing season.

Inoculated seeds of each of the three varieties were separately seeded into three 12" X 24" wooden flats. Each flat was filled with a steam sterilized soil media composed of 1/3 peat, 1/3 sand and 1/3 soil. A fungicide (Ferbam) was added during the first watering to control damping-off.

Six weeks before each segment of the field experiment was initiated the flats were seeded and put into a greenhouse where the crownvetch seedlings were grown. The seedlings were watered when the soil media started to dry, indicating a need for water. No lime or fertilizer was added to the soil before or during the six week growing period.

2. Treatments. The field plot was located on the University farm in South Deerfield, Massachusetts. The soil was the same type (Hadley silt loam) that was used in the growth chamber experiments. Soil tests indicated that the pH of the soil was 6.5 and was of high fertility. No lime, fertilizer or soil amendments were added to the soil.

Six week old seedlings of the three crownvetch varieties (3.0 to 5.6 cm in height) were transplanted into the field on three different planting dates and grown for 90 days. These dates, April 29, May 15 and June 9, 1969, corresponded with the calculated day lengths of 16, 17 and 18 hours, twilight included. Hereafter the three growth periods (April 29 to July 28, May 15 to August 12 and June 9 to September 5) will be designated as Series I, Series II and Series III, respectively.

Day length calculations were made from the American Ephemeris and Nautical Almanac (89). Daily mean temperatures were calculated from recordings made on a Taylor Seven Day Temperature Recorder that had previously been calibrated at several different temperatures with a mercury thermometer. Rainfall was recorded at the U.S. Weather Station in Amherst, Massachusetts.

3. Experimental Design. On each of the three planting dates crownvetch seedlings were transplanted in a block of nine rows. Each row was planted to a separate variety and replicated three times at random within each block. The seedlings were watered immediately after transplanting. Plants were set 8" apart in rows 48" wide to facilitate hand tractor cultivation. Each row consisted of 126 plants of one of the three varieties.

The statistical design of this experiment was a split-plot consisting of three separate plots--each representing a planting date. The analysis of variance was determined by computor and means were analyzed by the Duncan's New Multiple Range Test at the 5% level.

4. Observational Procedures. Starting with the day a block of plants was transplanted, 45 plants of each of the three varieties (15 per row) were harvested at random and observations made. This was done every 15 days until the termination of the growing period for each block (90 days). This procedure was repeated for plants set out at each planting date, so that plants from each block were harvested seven times for a total of 945 plants being removed from the field. In the entire field study there were 2835 plants (from 3 blocks) removed from the soil. There were six observations made on each plant to give a total of 17,010 observations.

Plants were removed from the field with as much soil around the roots as possible and placed into containers for transport. The roots were washed with a slow stream of water until all the soil was removed.

It was noticed that some root and nodule losses occurred during the removal of the plant from the field, in transport, and during washing of the roots. Attempts were made to correct this but these losses were unavoidable.

After the plants were washed the shoot and root lengths were recorded in centimeters and nodule counts made, the shoot and roots were separated and oven dried in paper bags at 95°F-115°F for 3 days. After drying, the plant parts were weighed on a Mettler gram scale. The shoot/root ratio was calculated from the dry weights of the shoots and roots.

B. Results

I. Series I (April 29 to July 28)

Environmental Conditions

Photoperiod. The calculated photoperiod, when the seedlings of crownvetch were transplanted, on April 29, 1969, was 16 hours and 7 minutes. As the 90 day growth period progressed, the maximum photoperiod increased to 18 hours and 9 minutes until June 22 (after 55 days of plant growth) and then decreased to 17 hours and 3 minutes at the end of the growth period on July 28.

The duration of these photoperiods are calculated for cloudless days. If cloud cover is present, the photoperiod will be shorter in duration than the calculated value (Figure 8).

Temperature. Although there were large fluctuations between the day and night temperatures and between the average daily temperatures the average monthly temperatures for May and July were close to 1°F of being normal. The average temperature for June was 2.7°F above normal (88) (Tables 9, 10 and Figure 9 A).

Rainfall. Rainfall was lower than normal for the months of May and June and the first 28 days of July. Normal temperatures and rainfall are based on averages from data of the years 1931-1960 (88), (Table 10 and Figure 10).

Shoot Height. Crownvetch grew relatively slow during the first half of the growth period. The average plant height of all varieties at the time of transplanting was 4.58 cm. After 43 days of growth in the field the average shoot

FIGURE 8

HOURS OF POSSIBLE SUNLIGHT PLUS TWILIGHT OF THE THREE SERIES OF PLANTINGS AT SOUTH DEERFIELD, MASSACHUSETTS

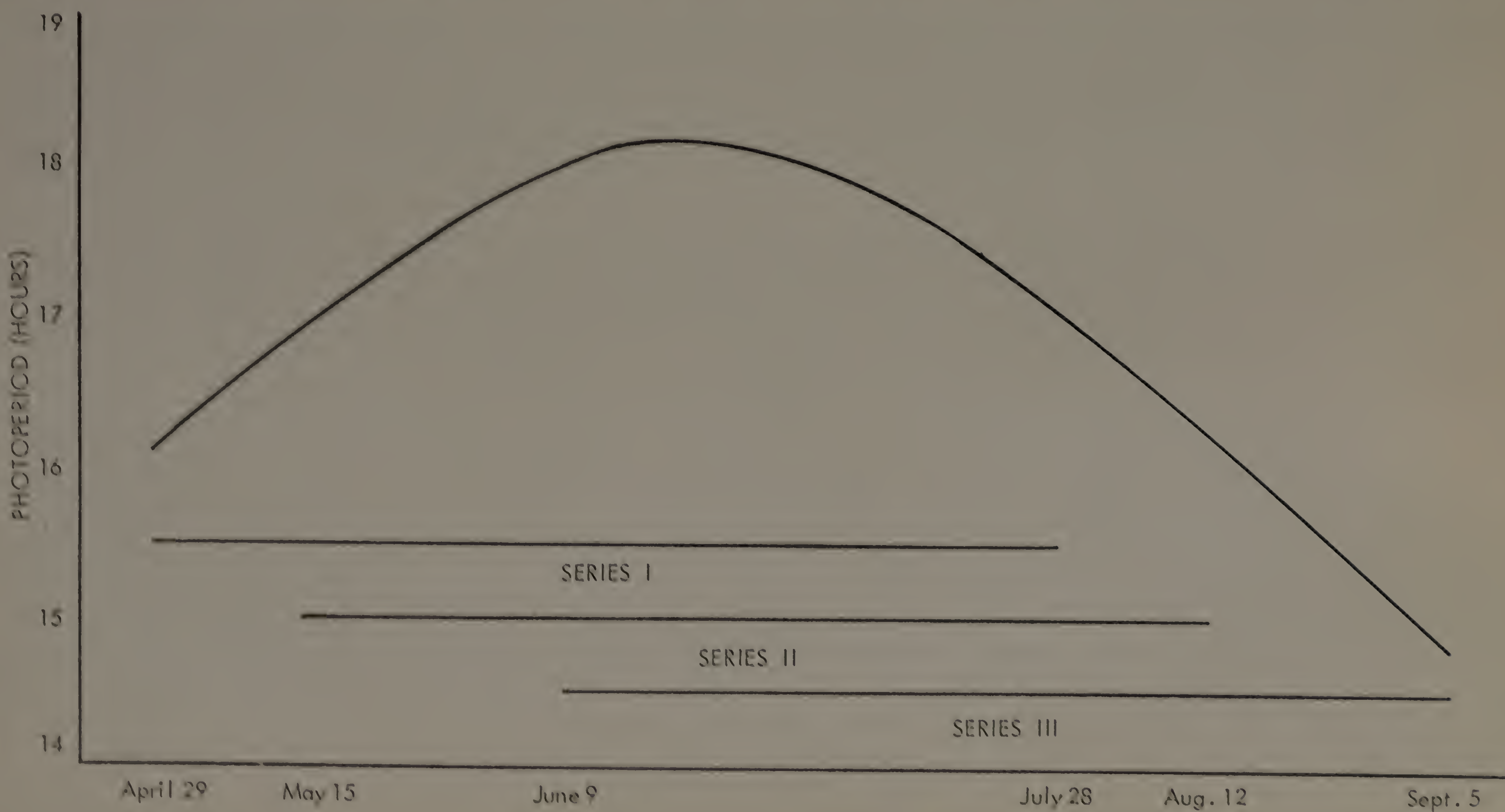


TABLE 9

PRECIPITATION AND DAILY TEMPERATURES FROM APRIL 29 TO SEPTEMBER 5, 1969

	Temp. - °F			Rain		Temp. - °F			Rain
Date	Max.	Min.	Avg.	Inches	Date	Max.	Min.	Avg.	Inches
4/29	82	68	75	-	6/ 1	80	47	64	-
4/30	68	44	56	.1	6/ 2	82	57	70	-
5/1	66	32	49	-	6/ 3	79	59	69	-
5/2	69	30	50	-	6/ 4	73	49	61	-
5/3	78	47	63	-	6/ 5	73	47	60	-
5/4	76	41	59	-	6/ 6	79	48	64	-
5/5	72	35	54	-	6/ 7	80	50	65	.3
5/6	68	27	48	-	6/ 8	82	54	68	.1
5/7	68	31	50	-	6/ 9	84	56	70	-
5/8	59	35	47	.2	6/10	89	47	68	-
5/9	63	57	60	.5	6/11	89	50	70	-
5/10	63	41	52	-	6/12	93	56	75	-
5/11	64	39	52	.3	6/13	92	65	79	-
5/12	61	31	46	-	6/14	77	68	73	.6
5/13	63	31	47	-	6/15	72	68	70	1.5
5/14	64	39	52	.1	6/16	75	61	68	-
5/15	68	32	50	-	6/17	79	53	66	-
5/16	75	49	55	-	6/18	76	58	67	.1
5/17	86	46	66	-	6/19	76	61	69	-
5/18	84	56	70	-	6/20	83	64	74	-
5/19	76	61	69	.4	6/21	77	59	68	-
5/20	71	64	68	.7	6/22	80	57	69	-
5/21	70	46	58	-	6/23	64	55	60	.7
5/22	81	50	66	-	6/24	63	57	60	-
5/23	69	46	58	-	6/25	89	60	75	-
5/24	59	54	57	-	6/26	86	54	70	-
5/25	75	53	64	.3	6/27	93	66	80	-
5/26	73	46	60	-	6/28	95	70	83	-
5/27	75	38	57	-	6/29	94	63	78	-
5/28	76	46	61	-	6/30	96	62	79	-
5/29	92	57	75	.3	7/ 1	87	69	78	-
5/30	84	57	71	-	7/ 2	89	56	73	-
5/31	50	50	66	-	7/ 3	81	55	68	-

TABLE 9 (continued)

PRECIPITATION AND DAILY TEMPERATURES FROM APRIL 29 TO SEPTEMBER 5, 1969

	Temp. - °F			Rain		Temp. - °F			Rain
Date	Max.	- Min.	Avg.	Inches	Date	Max.	- Min.	Avg.	Inches
7/ 4	93	56	75	.1	8/ 6	83	66	75	-
7/ 5	84	65	75	-	8/ 7	87	64	76	-
7/ 6	91	63	77	-	8/ 8	80	67	74	.2
7/ 7	81	55	68	-	8/ 9	83	65	74	-
7/ 8	89	53	71	-	8/10	71	66	69	.2
7/ 9	89	54	72	-	8/11	80	60	70	-
7/10	84	55	70	-	8/12	83	62	73	-
7/11	85	66	76	-	8/13	87	61	74	-
7/12	73	66	70	.3	8/14	89	64	77	-
7/13	69	64	67	.6	8/15	81	64	73	-
7/14	82	61	72	-	8/16	84	72	78	-
7/15	94	61	78	-	8/17	85	72	79	.2
7/16	101	67	84	-	8/18	86	70	78	-
7/17	94	70	82	-	8/19	80	65	73	-
7/18	90	70	80	-	8/20	82	57	70	-
7/19	82	67	75	-	8/21	79	53	66	-
7/20	80	67	74	-	8/22	83	50	67	-
7/21	77	66	72	.2	8/23	86	55	71	-
7/22	80	66	73	-	8/24	87	60	74	-
7/23	75	62	69	-	8/25	90	64	77	-
7/24	81	60	71	-	8/26	80	62	71	-
7/25	84	56	70	-	8/27	79	49	64	-
7/26	69	64	67	-	8/28	79	53	66	-
7/27	68	67	68	-	8/29	88	59	74	-
7/28	74	67	71	4.1	8/30	88	63	76	-
7/29	76	70	73	.3	8/31	85	64	75	-
7/30	79	60	75	.3	9/ 1	88	66	77	-
7/31	86	65	76	-	9/ 2	81	66	74	.2
8/ 1	85	66	76	.2	9/ 3	67	65	66	.1
8/ 2	88	71	80	-	9/ 4	76	65	71	-
8/ 3	87	68	78	-	9/ 5	71	65	68	-
8/ 4	70	67	69	4.5					
8/ 5	74	68	71	.1					

TABLE 10

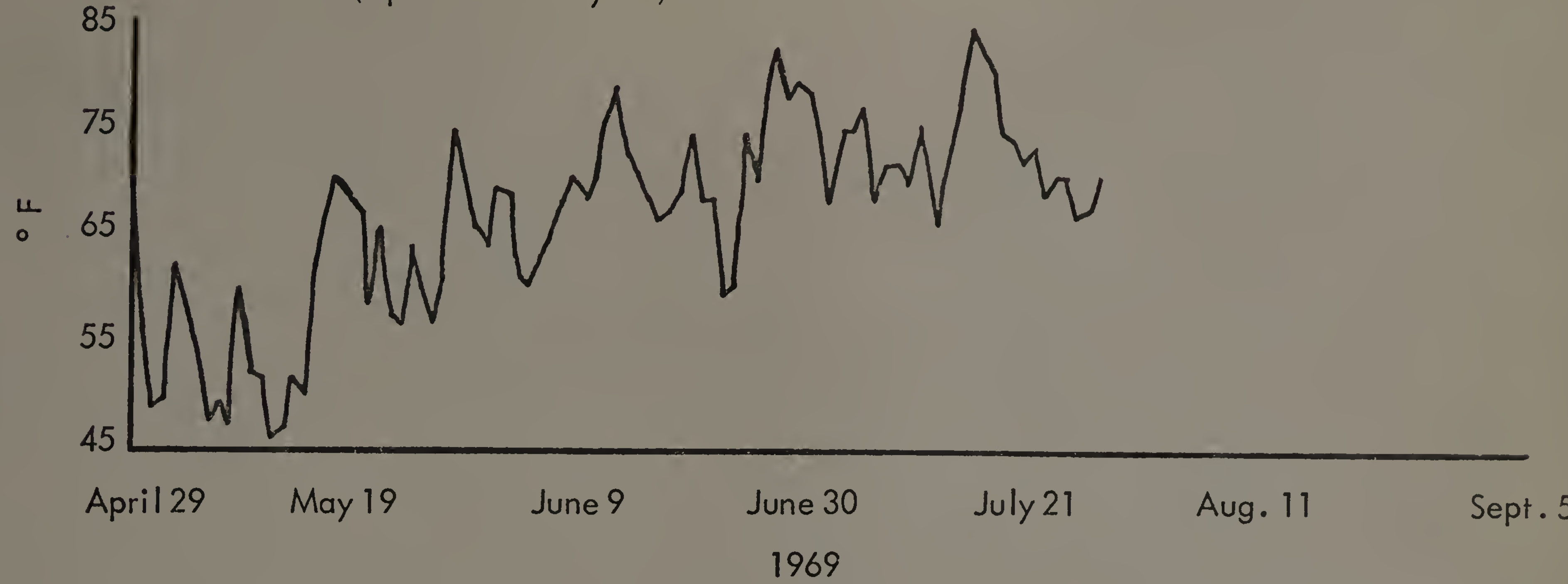
AVERAGE MONTHLY TEMPERATURES AND TOTAL RAINFALL AT SOUTH DEERFIELD, MASSACHUSETTS, FROM MAY TO SEPTEMBER 1969

	TEMPERATURE - °F		RAINFALL - INCHES	
Month	Avg.	Departure from Normal	Total	Departure from Normal
May	58.0	.0	2.8	- 1.0
June	69.5	+ 2.7	3.3	- .7
July	72.9	+ 1.2	5.9	+ 2.1
August	72.8	+ 3.2	5.4	+ 1.5
September	63.4	+ 1.4	2.9	+ 1.4

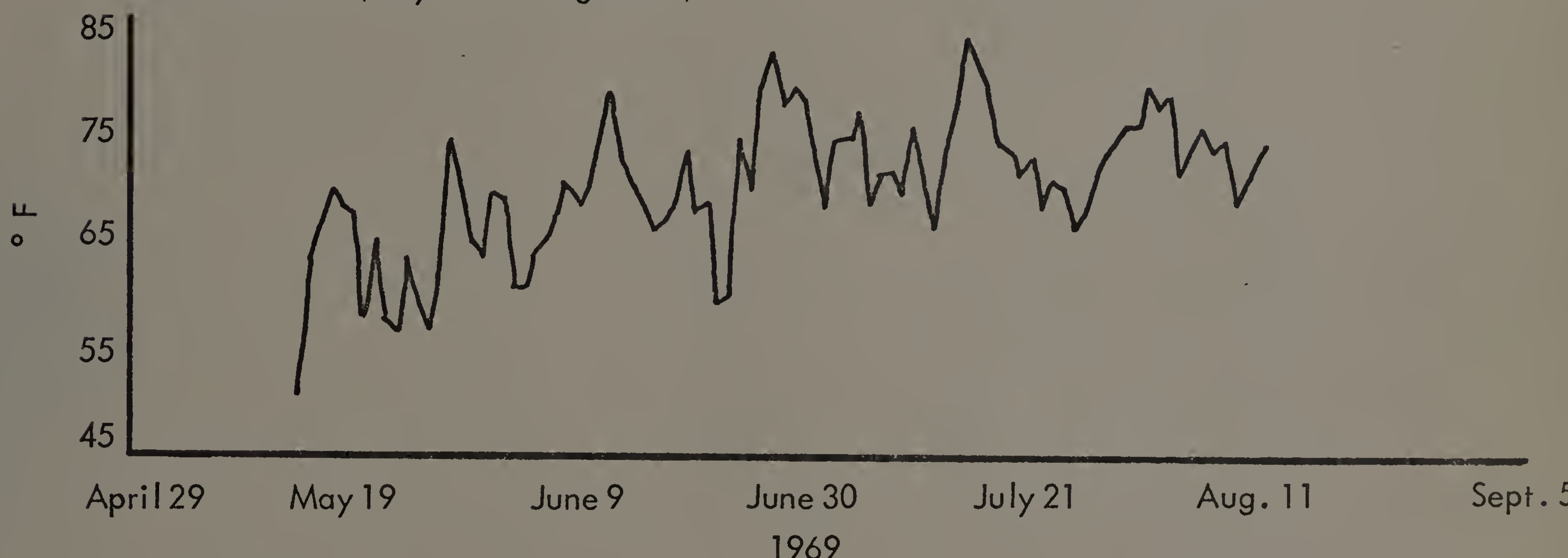
FIGURE 9

DAILY MEAN TEMPERATURES OF THE THREE SERIES OF PLANTINGS AT SOUTH DEERFIELD, MASS.

A. SERIES I (April 29 to July 28)



B. SERIES II (May 15 to August 13)



C. SERIES III (June 9 to September 5)

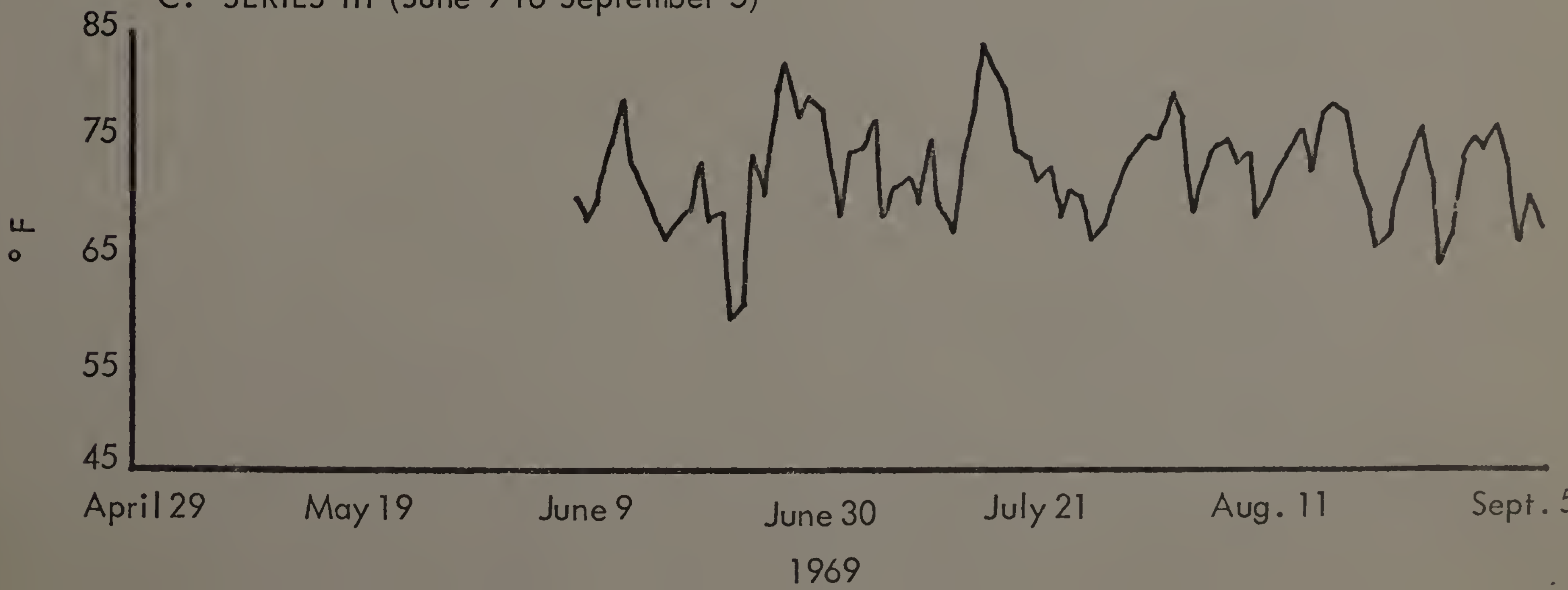
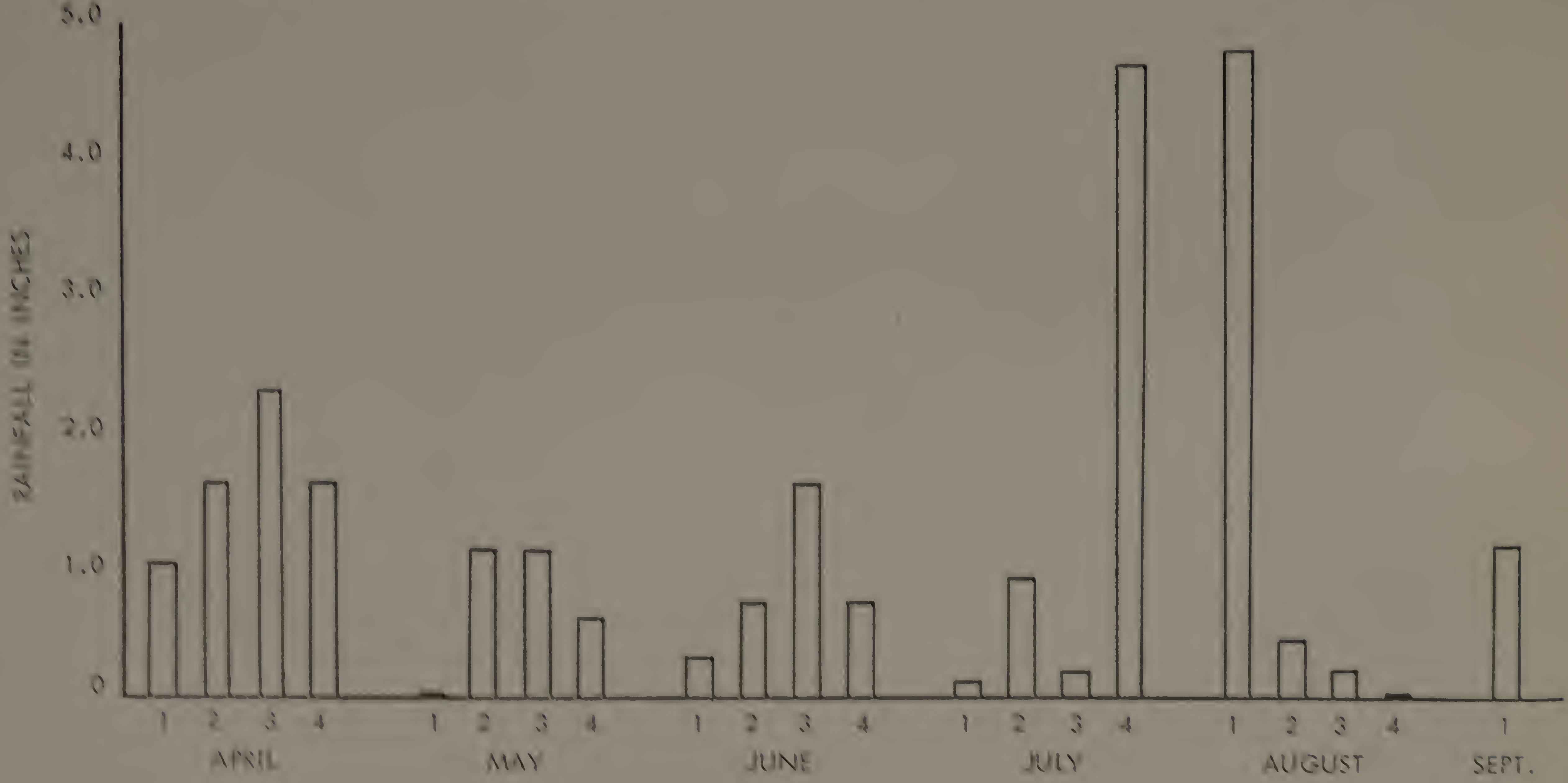


FIGURE 10

WEEKLY AVERAGE RAINFALL FROM APRIL TO SEPTEMBER 1969 AT SOUTH DEERFIELD, MASSACHUSETTS



height increased to 7.63 cm. Shoot height from that time on increased at a greater rate. As indicated by the data for the July 28th harvest, shoot height increased very rapidly from July 7 to July 28. Plant height at the last harvest date averaged 70.96 cm. The height of these plants was significantly taller than those plants grown in Series II and III (Table 11 and Figure 11 A).

There was very little difference in plant height between the three varieties. The only statistically significant difference in plant height was between Chemung and the other varieties at the last harvest date (after 90 days growth). Chemung averaged 6.09 cm higher than its nearest competitor, Penngift (Table 12).

Root Length. The root length of crownvetch increased constantly throughout most of the growing season. The average root length at 90 days growth was 57.9 cm. This was the longest root length (statistically significant) of the three growth periods (Table 11). A slight decline in the rate of increase in root length occurred in early July as shown by the data from the July 7th harvest (Figure 11 B).

During the period of the most rapid root growth, from July 7 on, Penngift consistently produced shorter roots than either of the other two varieties. Data from the July 7th harvest show this fact to be statistically significant (Table 12 and Figure 12 B).

Shoot Dry Weight Production. The shoot dry weight of crownvetch plants grown during the first ten weeks increased very slowly. When transplanted into the field the average shoot weight (for all varieties) was .01 grams/plant and by the end of the 7th week the average was 2.73 grams/plant. During the last three weeks of Series I the shoot dry weight increased at a very rapid rate and

TABLE 11

AVERAGE LENGTH AND WEIGHT OF SHOOTS AND ROOTS, NUMBER OF NODULES PER PLANT AND SHOOT/ROOT RATIO OF CROWNVETCH HARVESTED SEVEN TIMES DURING SERIES I, II AND III

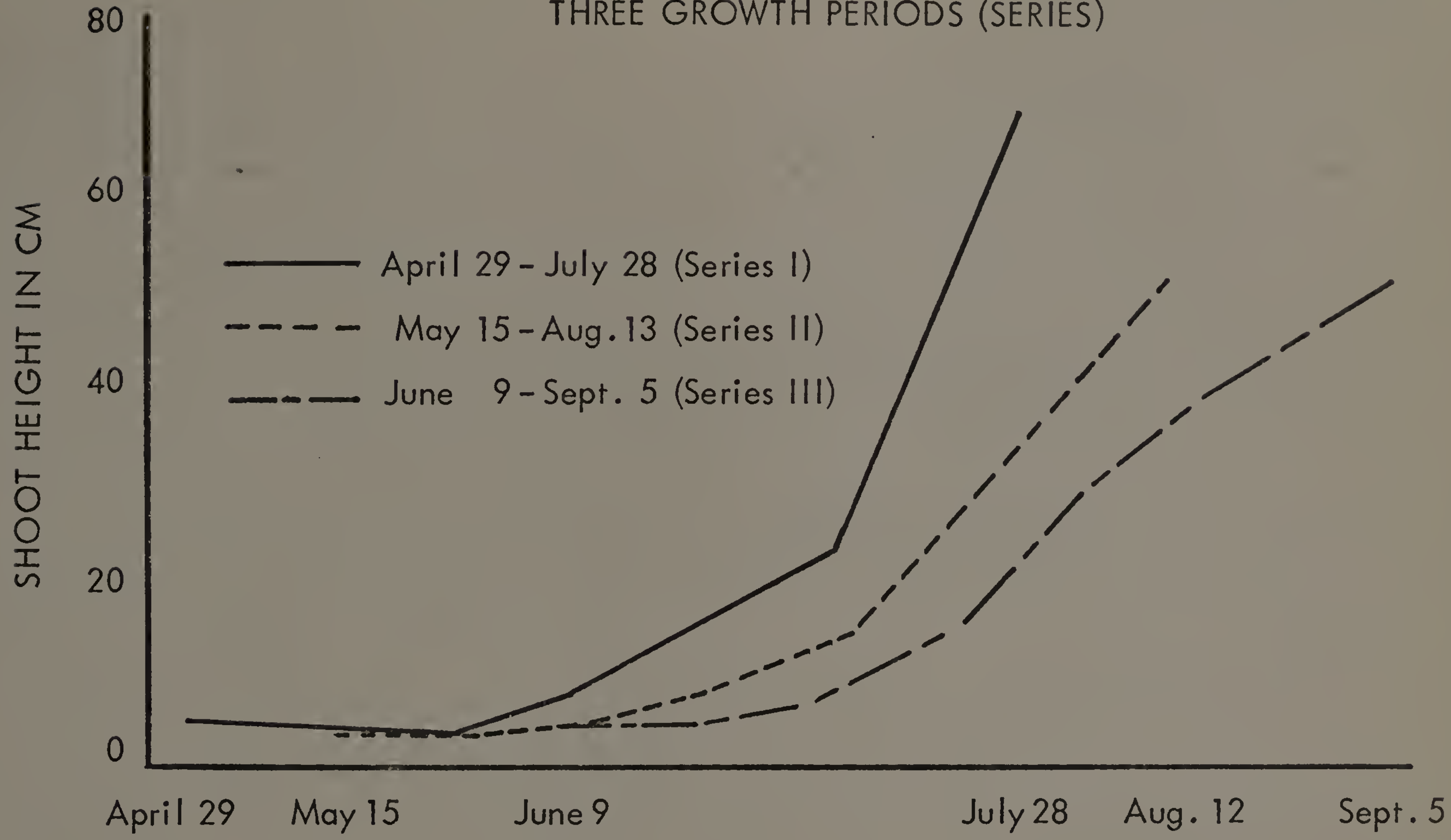
Harvest Date 1969	Series	Shoot Height cm	Root Length cm	Shoot dry Weight g	Root dry Weight g	Nodule Number	Shoot/Root Ratio
April 29	I	4.58 ab[x/]	8.29 a[y/]	.010 a	.006 a	2.02 ab	1.82 de
May 15	II	3.41 a	9.64 ab	.014 a	.010 a	2.19 ab	1.48 cd
June 9	III	3.96 ab	10.51 abc	.020 a	.009 a	1.41 a	2.27 fg
May 14	I	3.89 ab	9.09 ab	.017 a	.016 a	5.06 abc	1.05 a
May 30	II	3.20 a	10.32 ab	.022 a	.020 a	3.68 abc	1.15 ab
June 23	III	4.39 ab	11.33 bc	.030 a	.020 a	4.21 abc	1.50 cd
May 27	I	3.83 ab	10.86 bc	.039 a	.037 a	8.49 bcd	1.06 a
June 12	II	4.39 ab	11.29 bc	.067 a	.050 a	12.60 def	1.37 abc
July 7	III	6.74 bc	14.57 d	.144 a	.051 a	12.38 def	2.83 hi
June 10	I	7.63 c	12.73 cd	.203 a	.099 a	16.66 fg	2.03 ef
June 23	II	7.77 c	13.16 cd	.182 a	.117 a	17.10 fg	1.58 cd
July 22	III	15.52 d	24.20 fg	.853 ab	.283 ab	15.03 def	3.02 i
June 23	I	14.97 d	22.48 ef	.668 ab	.280 ab	15.96 efg	2.38 fg
July 10	II	14.27 d	20.41 e	.846 ab	.337 ab	12.63 def	2.52 gh
August 5	III	27.98 f	29.39 h	3.887 c	.932 bc	14.07 def	4.15 l
July 7	I	22.94 e	25.83 g	2.730 bc	.732 abc	9.62 cde	3.79 k
July 24	II	29.47 f	28.33 h	3.692 c	1.118 c	16.03 efg	3.42 j
August 18	III	38.79 g	38.13 i	7.728 d	2.064 d	21.78 gh	3.73 jk
July 28	I	70.96 i	57.91 l	32.529 g	6.711 f	29.24 h	4.80 m
August 13	II	52.10 h	42.48 j	17.209 e	4.020 e	23.66 h	4.44 l
September 5	III	52.19 h	48.62 k	22.306 f	8.228 g	47.93 i	2.77 hi

x/ Each observation is a composite of the three crownvetch varieties (45 readings).

y/ Means in each column with a letter in common are not statistically significant at the 5% level according to the Duncan's New Multiple Range Test.

FIGURE 11

A. AVERAGE SHOOT HEIGHT IN CM OF CROWNVETCH GROWN DURING THREE GROWTH PERIODS (SERIES)



B. AVERAGE ROOT LENGTH IN CM OF CROWNVETCH GROWN DURING THREE GROWTH PERIODS (SERIES)

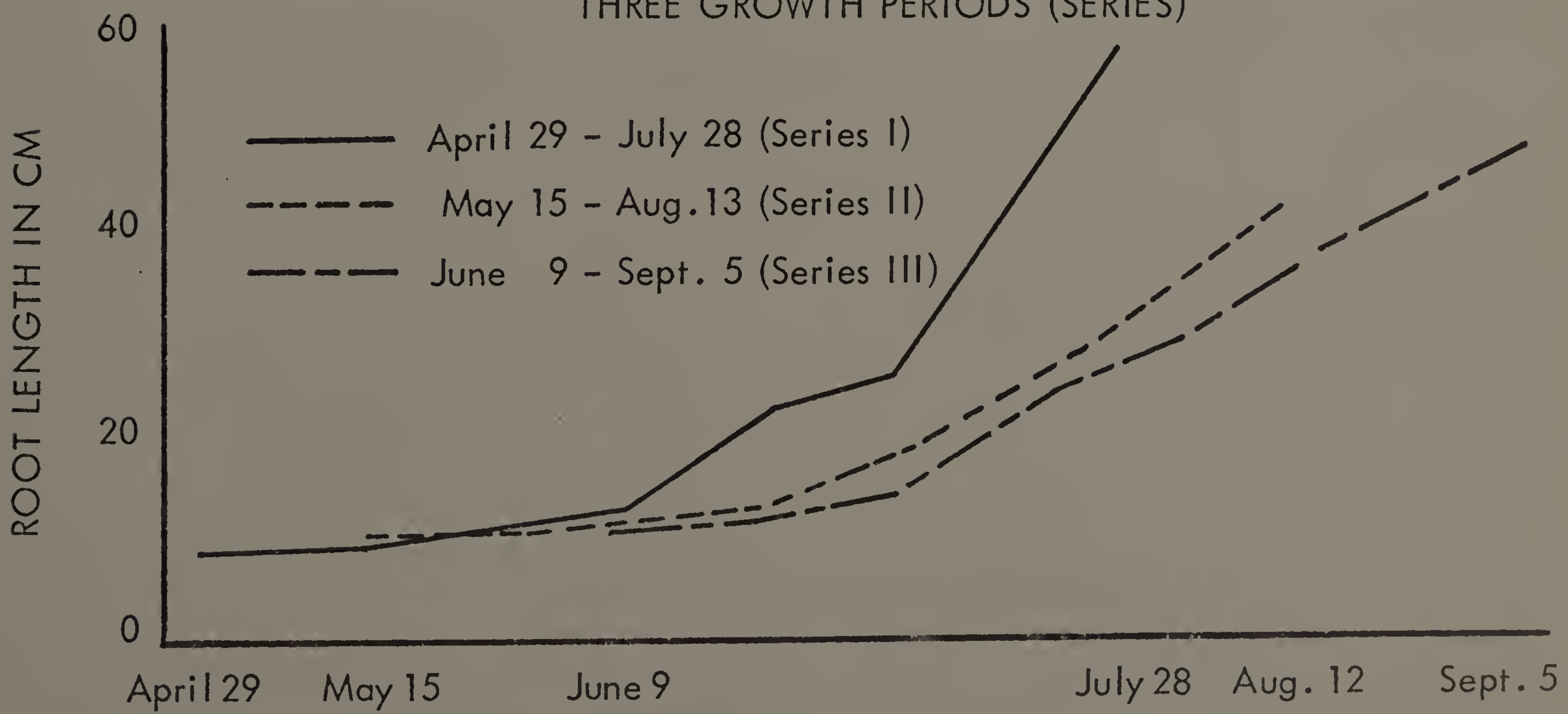


TABLE 12

AVERAGE LENGTH AND WEIGHT OF SHOOTS AND ROOTS, NUMBER OF NODULES/ PLANT AND SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES HARVESTED SEVEN TIMES DURING SERIES I (APRIL 29 TO JULY 28)

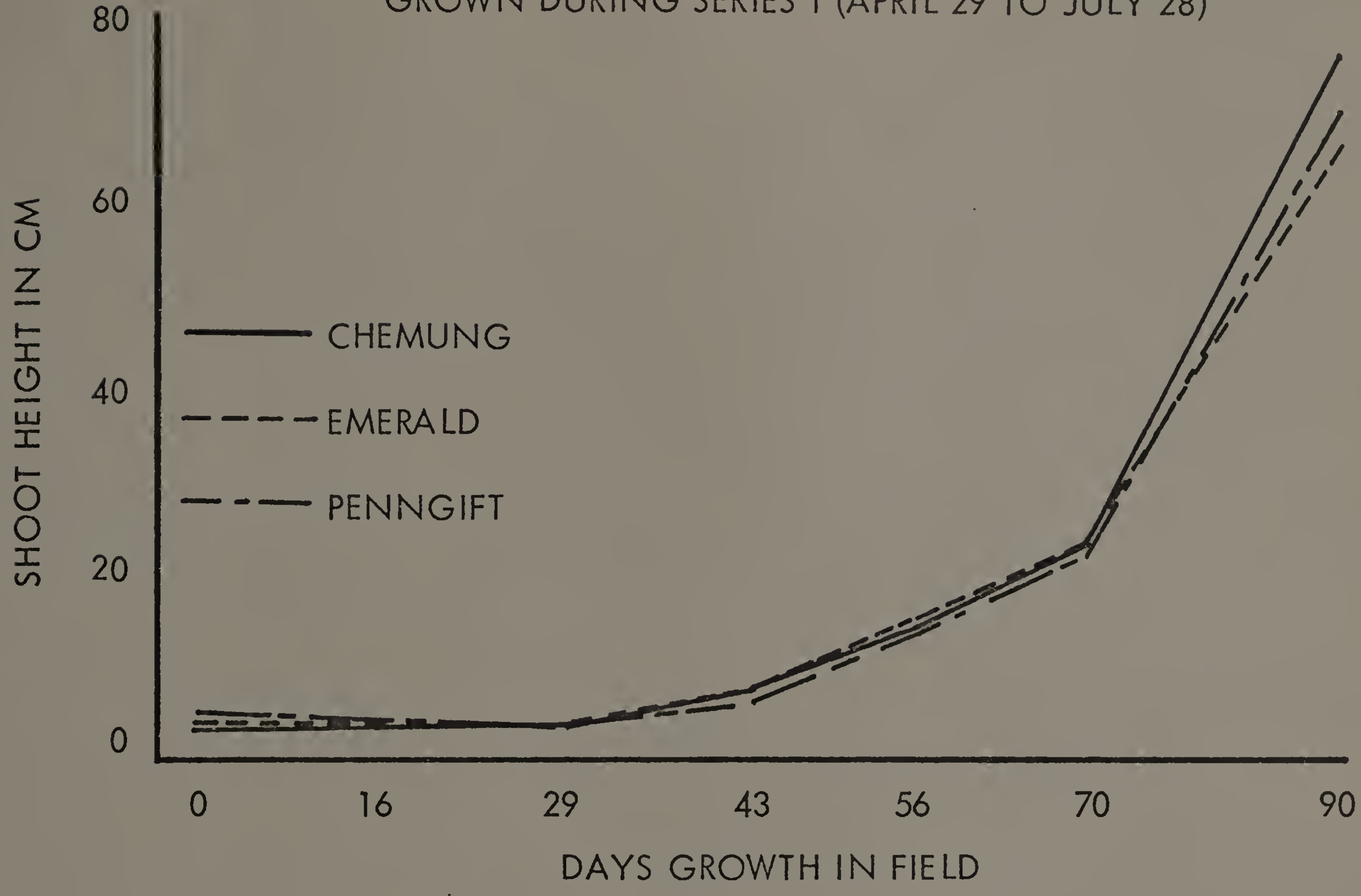
Harvest Date 1969	Var.	Shoot Height cm	Root Length cm	Shoot dry Weight g	Root dry Weight g	Nodule Number	Shoot/Root Ratio
April 29	C x/	3.63 a y/	8.68 ab	.010 a	.006 a	2.07 a-e	1.59 a-g
	E	4.59 a	8.28 a	.012 a	.007 a	1.51 abc	1.72 a-i
	P	5.45 a	7.90 a	.009 a	.004 a	2.44 a-e	2.15 e-m
May 14	C	3.93 a	9.29 abc	.016 a	.017 a	7.20 a-j	0.98 a
	E	3.83 a	9.71 abc	.020 a	.019 a	3.84 a-g	1.06 ab
	P	3.93 a	8.25 a	.014 a	.013 a	4.13 a-g	1.10 abc
May 27	C	3.75 a	11.41 a-f	.038 a	.039 ab	9.22 a-k	0.96 a
	E	3.73 a	10.75 a-f	.045 a	.040 ab	9.00 a-k	1.12 abc
	P	4.02 a	10.43 a-f	.034 a	.031 a	7.25 a-j	1.09 abc
June 10	C	7.87 a	12.95 b-f	.173 a	.099 ab	15.95 f-q	1.75 b-j
	E	8.55 a	12.95 b-f	.260 a	.109 ab	18.33 i-q	2.40 i-p
	P	6.47 a	12.30 a-f	.176 a	.090 ab	15.69 f-q	1.94 d-l
June 23	C	14.86 b	22.11 ghi	.660 a	.300 ab	14.74 e-q	2.21 f-n
	E	15.43 b	22.34 ghi	.787 a	.283 ab	17.31 h-q	2.78 m-s
	P	14.63 b	22.99 hij	.557 a	.257 ab	15.82 f-q	2.17 f-n
July 7	C	23.20 c	28.47 lmn	2.450 ab	.860 abc	10.58 a-m	2.91 n-u
	E	23.58 cd	26.65 j-m	3.427 abc	.740 ab	9.51 a-l	4.57 xyz
	P	22.03 c	22.37 ghi	2.313 ab	.597 ab	8.87 a-k	3.88 vw
July 28	C	76.42 m	58.05 u	33.950 g	7.070 i	20.38 k-q	4.80 yz
	E	66.13 l	59.63 u	36.823 g	7.120 i	40.02 s	5.17 z
	P	70.33 l	56.07 t	26.513 f	5.943 h	27.33 qr	4.44 xy

x/ Means in each column with a letter in common are not statistically significant at the 5% level according to the Duncan's New Multiple Range Test.

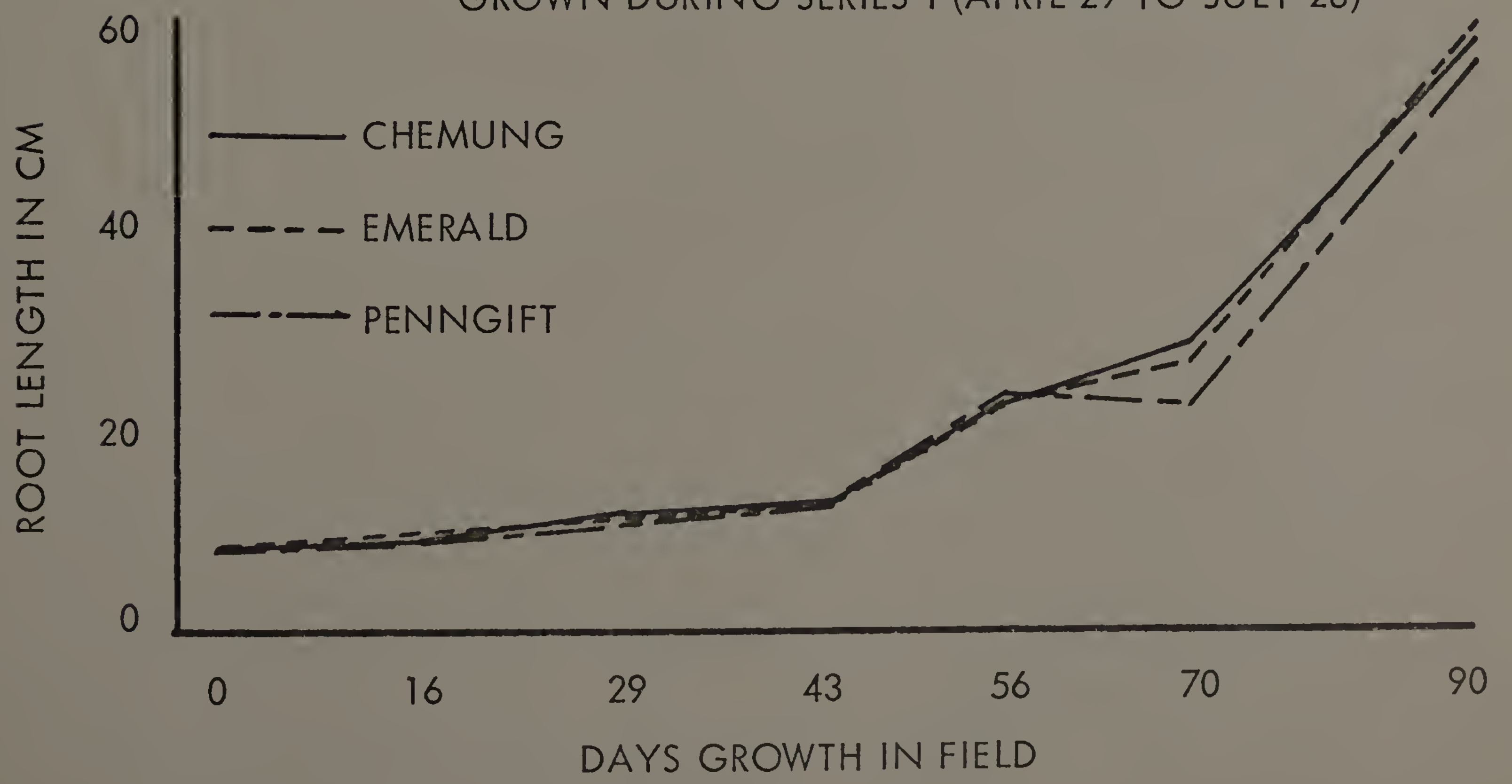
y/ C - Chemung; E - Emerald; P - Penngift.

FIGURE 12

A. AVERAGE SHOOT HEIGHT IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES I (APRIL 29 TO JULY 28)



B. AVERAGE ROOT LENGTH IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES I (APRIL 29 TO JULY 28)



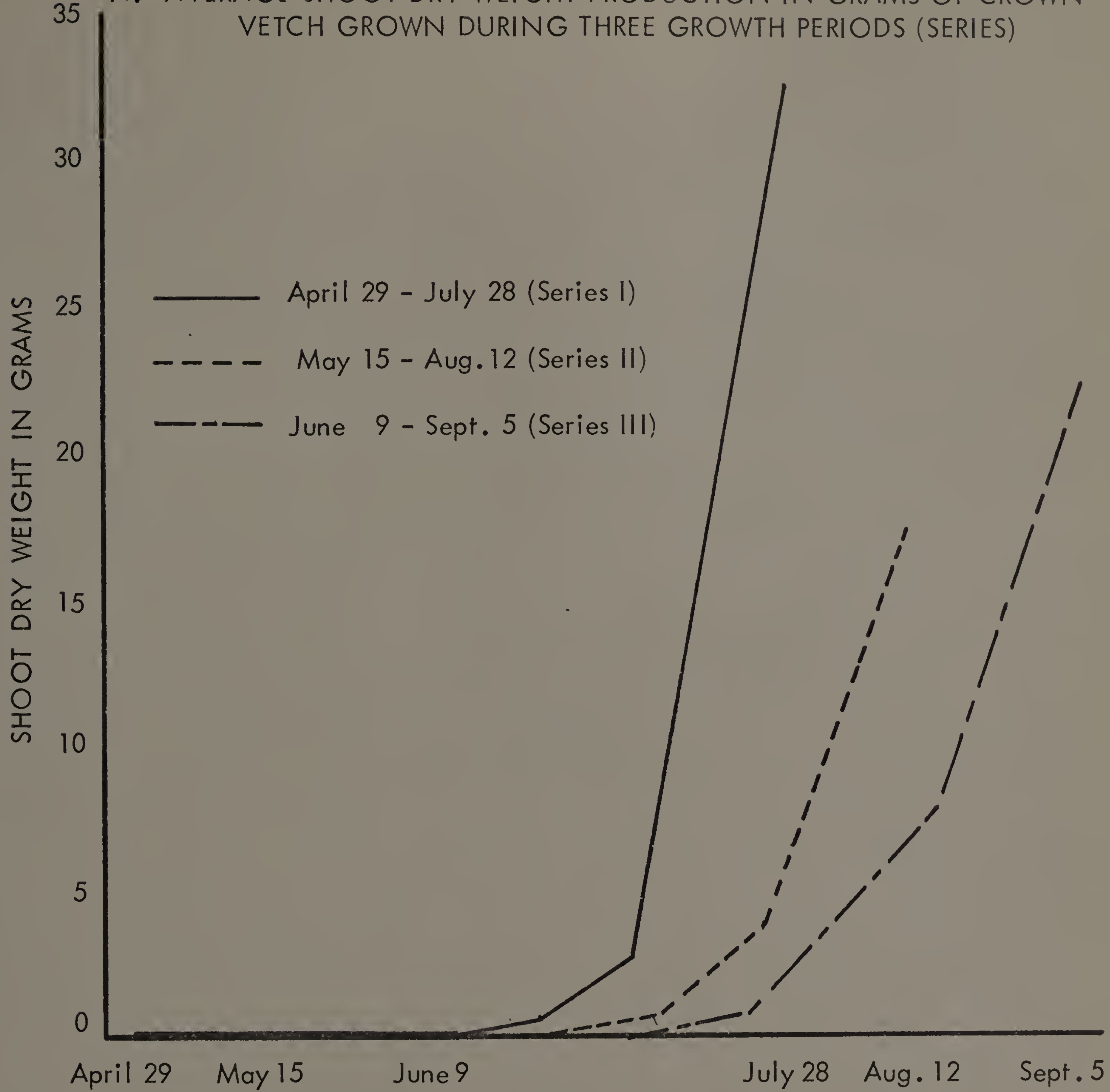
by the 90th day averaged 32.4 grams/plant. This yield was statistically significant from the shoot weight of plants in Series II and III. It was noticed that this sharp rise in shoot dry weight production occurred in each growth period but at different times (Table 11 and Figure 13 A).

There were no significant differences in shoot dry weight production between varieties during the first 70 days of growth; although Penngift did produce slightly less throughout this period. During the remaining three weeks in the field, differences in shoot weight between varieties became apparent. Maximum shoot dry weight was produced by Emerald (36.8 grams/plant) but was not statistically significant from Chemung (34.0 grams/plant). Penngift produced the least shoot dry weight (26.5 grams/plant) and was significantly different from the other varieties (Table 12 and Figure 14 A).

Root Dry Weight Production. Root dry weight production was far less than that of the aerial portion of the plant. The root weight during the first ten weeks increased from an average of .006 grams/plant to .732 grams/plant for all varieties. In the last three weeks there was a greater increase in root growth and final root dry weight was 6.7 grams/plant (Table 11 and Figure 13 B). As with shoot production the largest increases in root growth were apparent after the plants had been in the field for approximately 70 days. Varietal differences did not become apparent until the June 23rd harvest. From that date to July 28 the root dry weight production of Chemung and Emerald were almost identical and both were significantly higher than that of Penngift (Table 12 and Figure 14 B).

FIGURE 13

A. AVERAGE SHOOT DRY WEIGHT PRODUCTION IN GRAMS OF CROWN-VETCH GROWN DURING THREE GROWTH PERIODS (SERIES)



B. AVERAGE ROOT DRY WEIGHT PRODUCTION IN GRAMS OF CROWN-VETCH GROWN DURING THREE GROWTH PERIODS (SERIES)

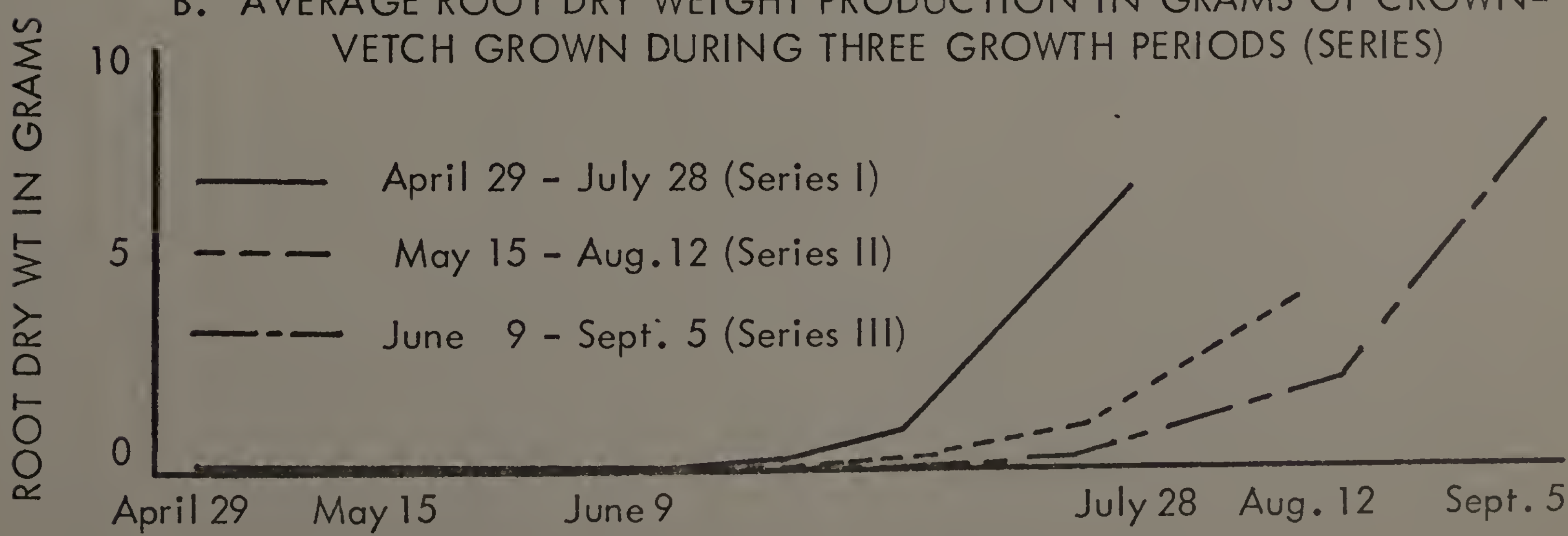
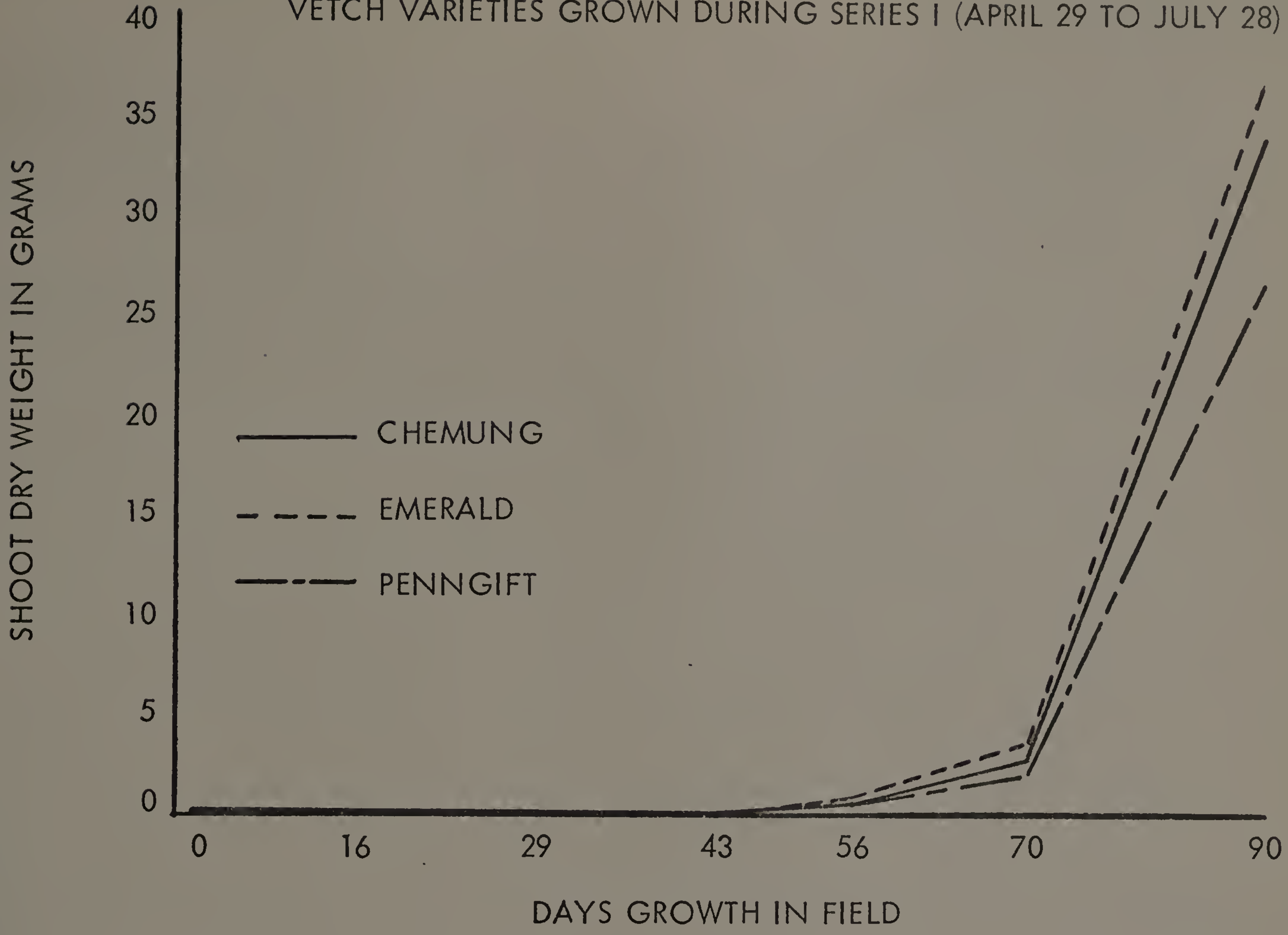


FIGURE 14

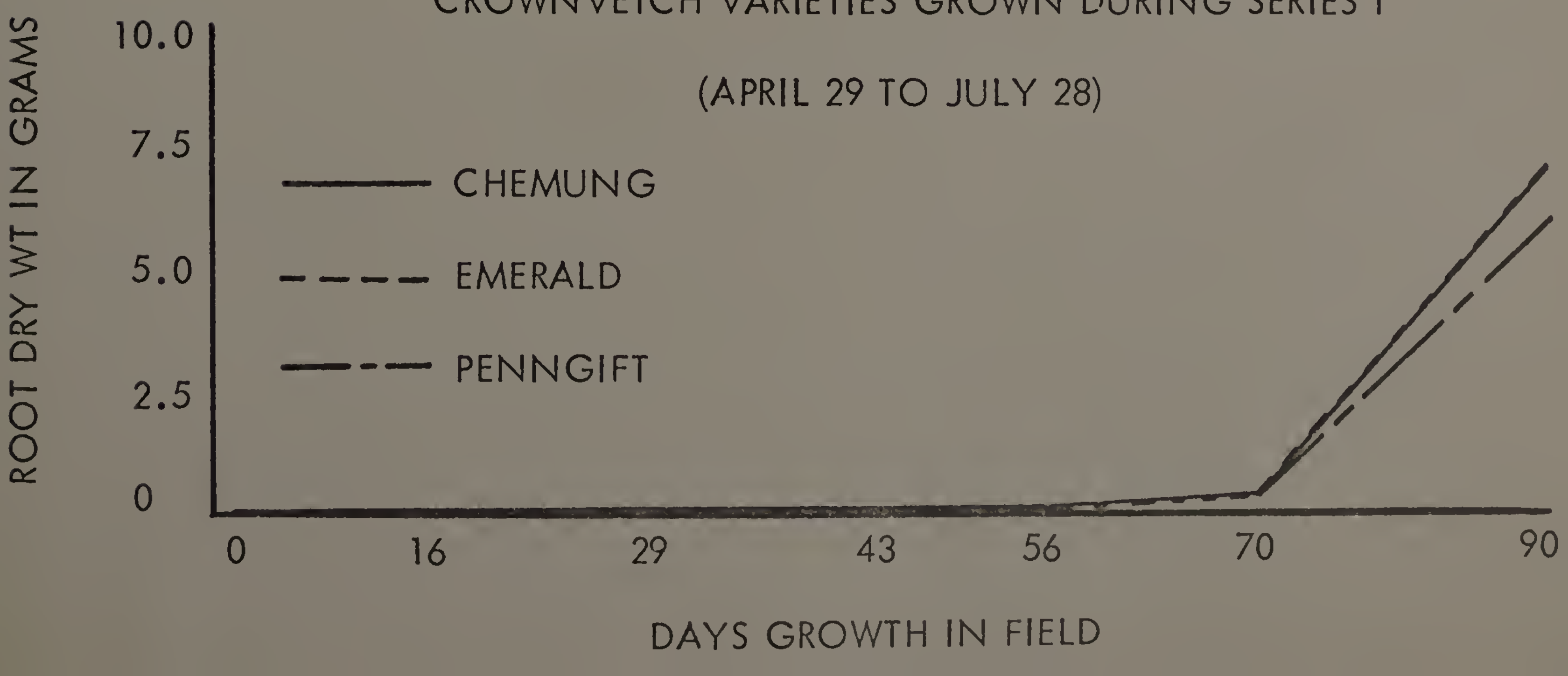
A. AVERAGE SHOOT DRY WEIGHT PRODUCTION IN GRAMS OF CROWN-VETCH VARIETIES GROWN DURING SERIES I (APRIL 29 TO JULY 28)



B. AVERAGE ROOT DRY WEIGHT PRODUCTION IN GRAMS OF THREE

CROWNVETCH VARIETIES GROWN DURING SERIES I

(APRIL 29 TO JULY 28)



Nodule Number. The average number of nodules per plant increased from 2.0 to 16.0 during the first eight weeks of growth. In the next two weeks the number of nodules decreased and a large decline was noted at the July 7th harvest. In the last three weeks of Series I, nodule growth increased significantly; final nodule count was 29.2/plant (Table 11 and Figure 15 A).

There were no significant differences in nodule number between varieties at each of the first six harvest dates. Data of the final harvest showed that Emerald produced far more nodules per plant when compared to the other varieties. This difference in nodule production was statistically significant (Table 12 and Figure 16 A).

Shoot/Root Ratio. The shoot/root ratio decreased from 1.8 to 1.0 during the first four weeks of the growth period. After the May 27th harvest the ratio steadily increased to a value of 4.8 by the 90th day (Table 11 and Figure 15 B). Trends for the shoot/root ratio of the three varieties were similar throughout the growth period. Emerald had the largest shoot/root ratio from May 14 on and was statistically significant from the other varieties at the sixth and seventh harvests (Table 12 and Figure 16 B).

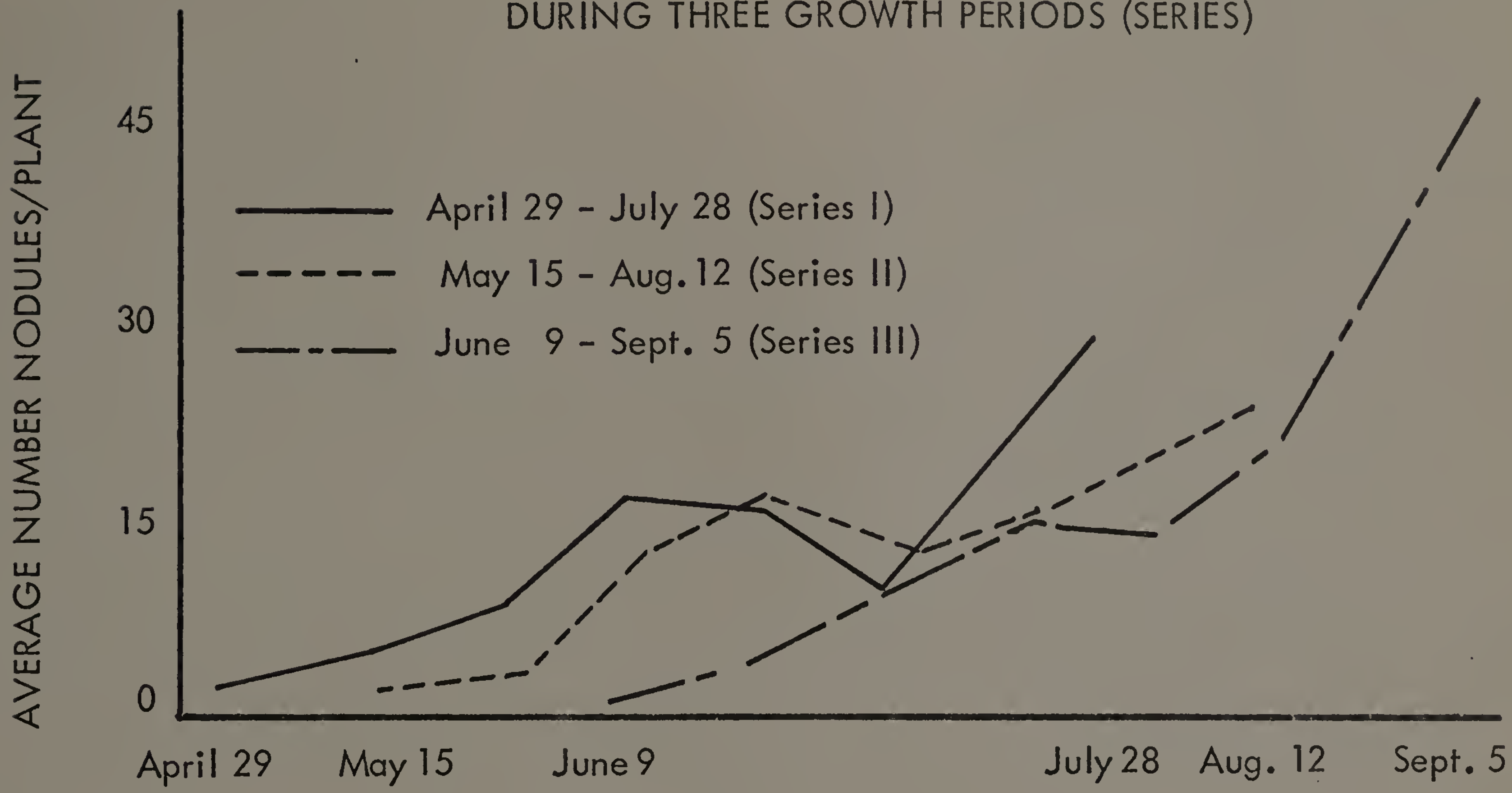
II. Series II (May 15 to August 13)

Environmental Conditions

Photoperiod. The second series was planted on May 15 to coincide with the calculated photoperiod of 17 hours (actual - 16 hours and 58 minutes). The longest day (June 22) occurred after 39 days of plant growth. The length of the photoperiod at the termination of this growth period was 16 hours and 13 minutes (Figure 8).

FIGURE 15

A. AVERAGE NODULE NUMBER PER PLANT OF CROWNVETCH GROWN DURING THREE GROWTH PERIODS (SERIES)



B. SHOOT/ROOT RATIO OF CROWNVETCH GROWN DURING THREE GROWTH PERIODS (SERIES)

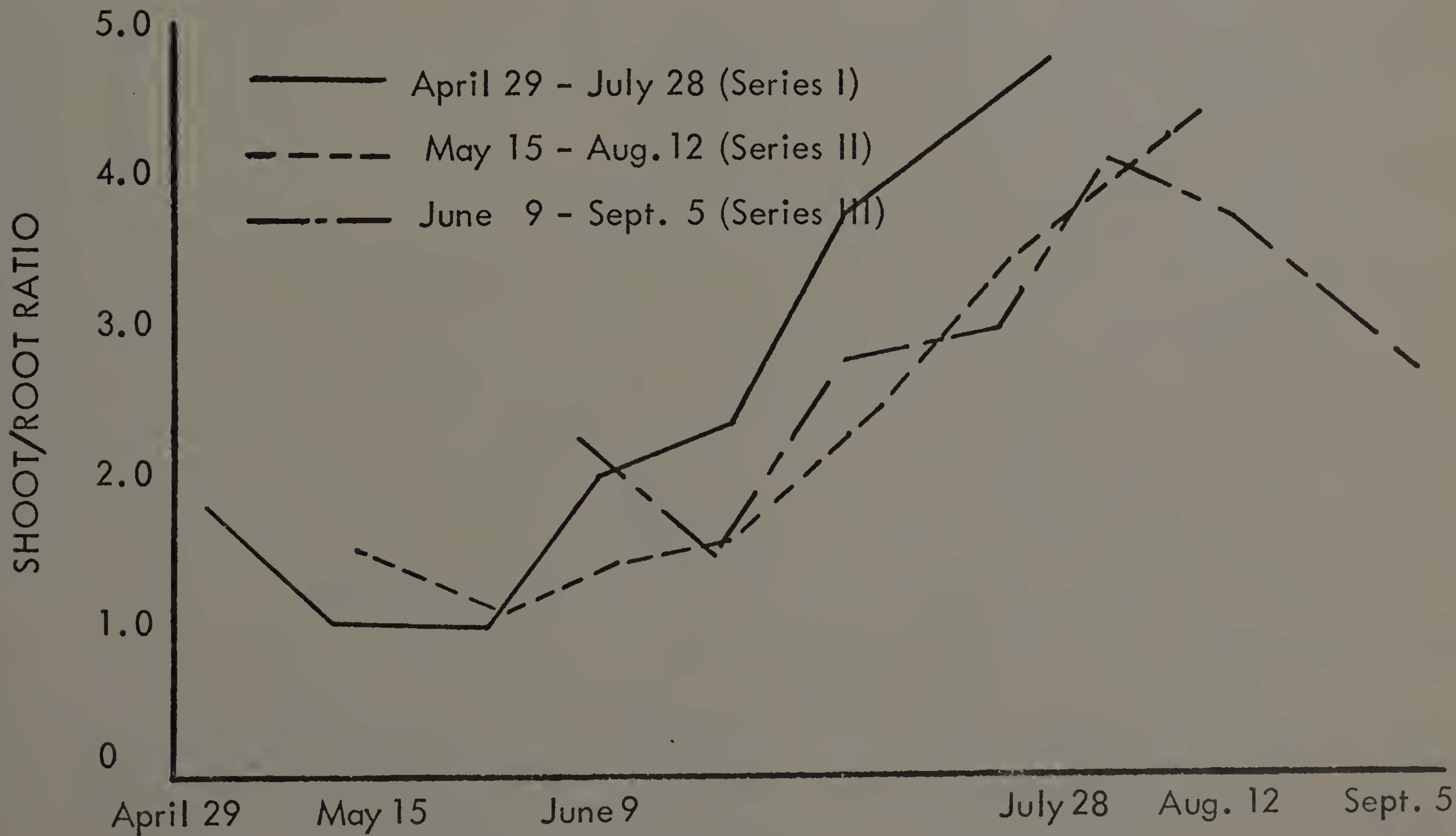
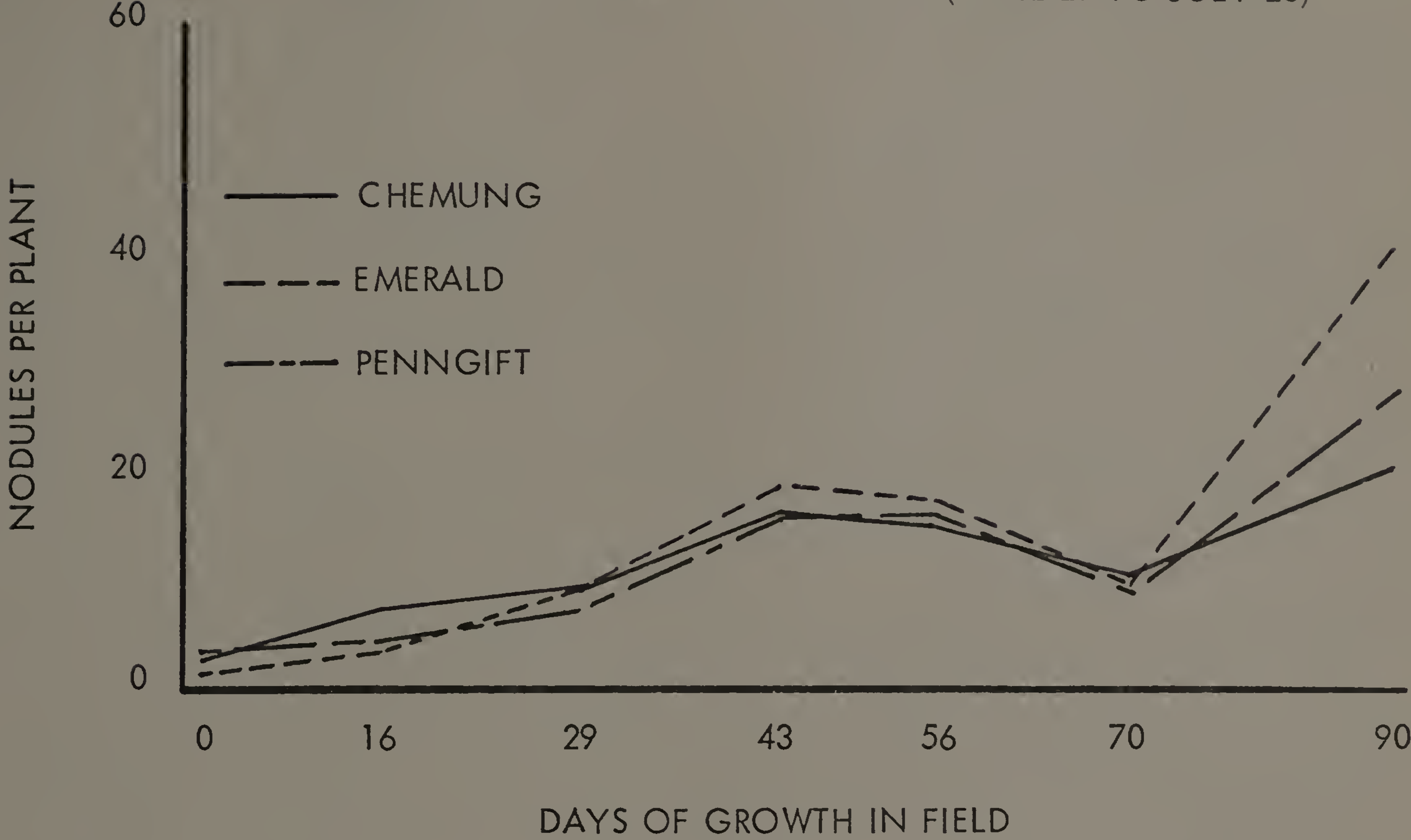
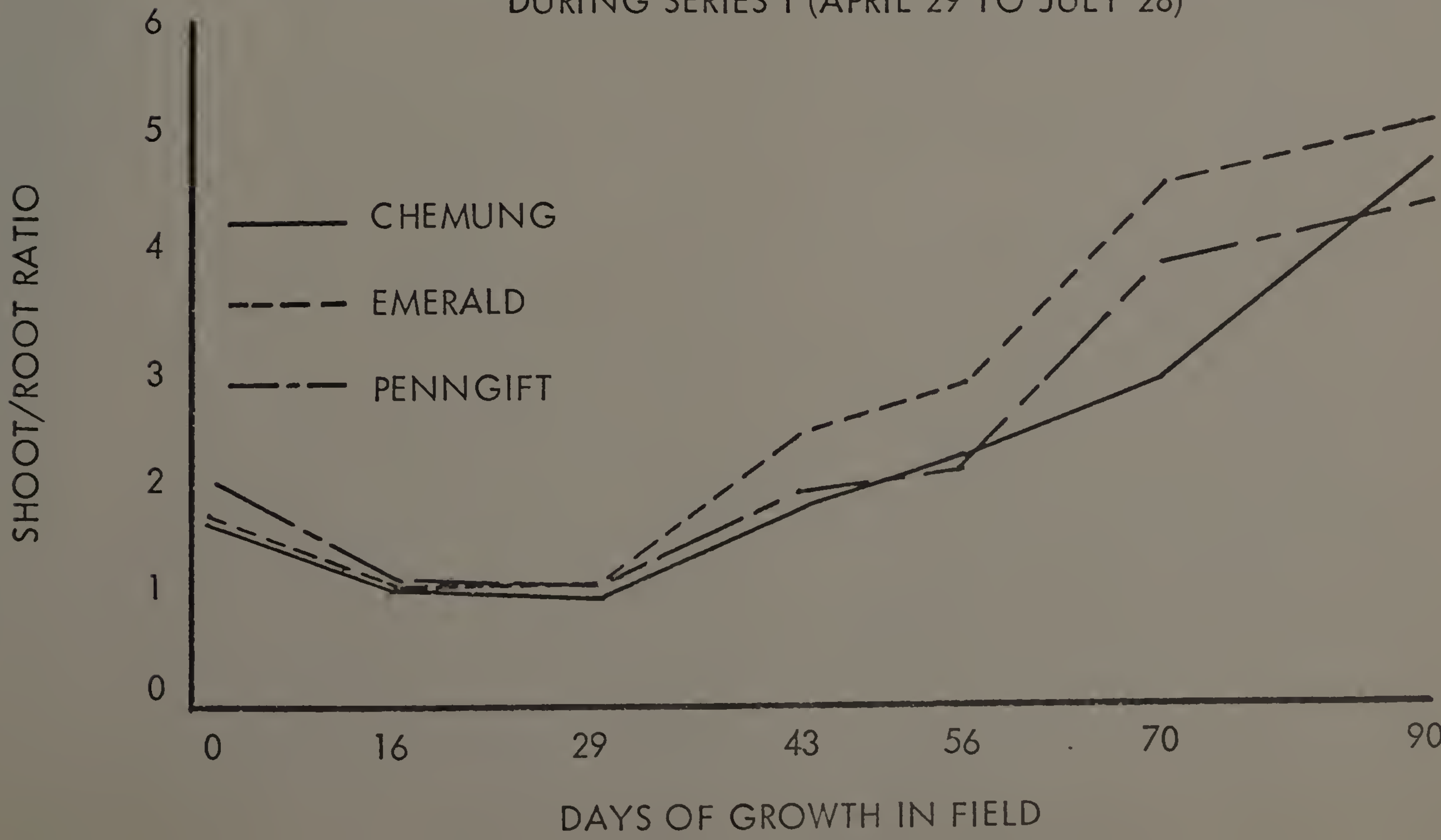


FIGURE 16

A. AVERAGE NODULE NUMBER PER PLANT OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES I (APRIL 29 TO JULY 28)



B. SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES I (APRIL 29 TO JULY 28)



Temperature. The average monthly temperature for May and July was about normal. June's average temperature was 2.7°F higher than normal and that of August was 3.2°F above normal. A ten day cool period started on July 19 and lasted until the 29th (Table 9, 10 and Figure 9 B).

Rainfall. During the first 74 days of the growth period rainfall was below normal. In the last 16 days rainfall was 9.9 inches, which was far above normal (Table 10 and Figure 10).

Shoot Height. The rate of increase in shoot height of crownvetch plants grown during the first 70 days was approximately the same as for those plants grown for the same period of time in the first series. Final shoot height in the second series (52.1 cm) was significantly less than that of the first (71.0 cm) (Table 11 and Figure 11 A).

Shoot height of all varieties was nearly the same for the first 10 weeks of plant growth. At the termination of the growth period the shoot height of Chemung and Penngift (59.1 and 56.9 cm, respectively) was significantly higher than that of Emerald, 40.3 cm (Table 13 and Figure 17 A).

Root Length. Root length of plants grown during the first 10 weeks increased similarly to that of plants in the first series. During the last three weeks of growth the rate of increase in root length was less than that of plants in the first series. This resulted in the lowest final root length of the three growth periods (Table 11 and Figure 11 B). Until the 6th harvest (at 70 days) the root length of all varieties was approximately the same, but at the end of the growth period the short root length of Emerald was statistically significant from the

TABLE 13

AVERAGE LENGTH AND WEIGHT OF SHOOTS AND ROOTS, NUMBER OF NODULES/ PLANT AND SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES HARVESTED SEVEN TIMES DURING SERIES II (MAY 15 - AUGUST 13)

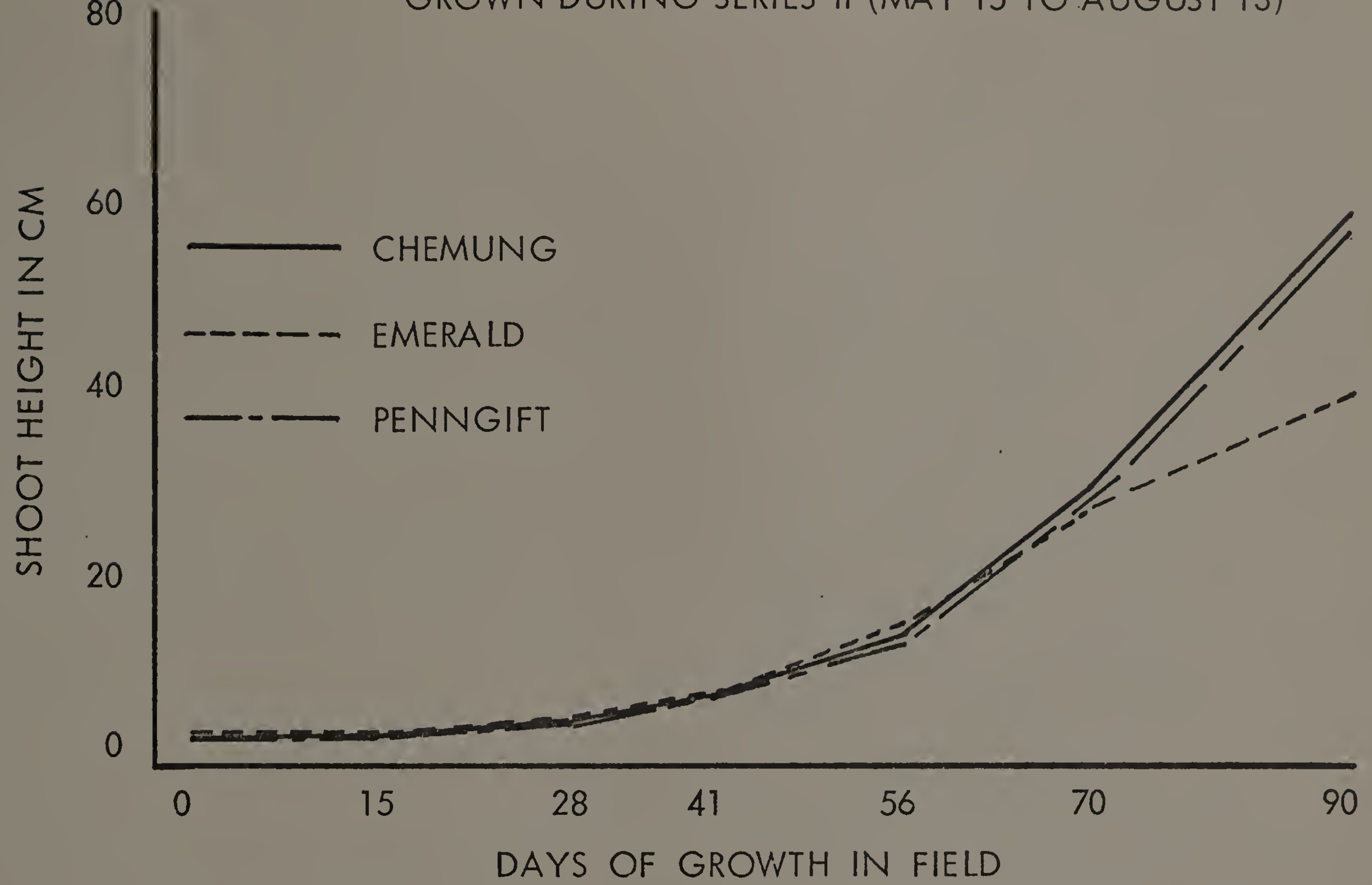
Harvest Date 1969	Var.	Shoot Height cm	Root Length cm	Shoot dry Weight g	Root dry Weight g	Nodule Number	Shoot/Root Ratio
May 15	C x/	3.16 a y/	9.99 a-e	.011 a	.008 a	1.18 ab	1.37 a-d
	E	3.85 a	10.34 a-e	.018 a	.015 a	5.09 a-h	1.25 a-d
	P	3.22 a	8.58 ab	.013 a	.007 a	0.31 a	1.83 c-k
May 30	C	3.03 a	9.57 abc	.019 a	.018 a	1.93 a-d	1.11 abc
	E	3.62 a	11.43 a-f	.031 a	.025 a	5.76 a-i	1.25 a-d
	P	2.95 a	9.96 a-e	.018 a	.016 a	3.36 a-f	1.08 abc
June 12	C	4.82 a	10.49 a-f	.061 a	.046 ab	9.75 a-l	1.40 a-e
	E	4.46 a	11.94 a-f	.080 a	.061 ab	16.42 g-q	1.33 a-d
	P	3.88 a	11.45 a-f	.060 a	.044 ab	11.62 a-o	1.37 a-d
June 25	C	7.83 a	12.34 a-f	.165 a	.104 ab	14.71 e-q	1.58 a-g
	E	7.74 a	13.94 def	.206 a	.133 ab	22.02 l-r	1.59 a-g
	P	7.75 a	13.21 c-f	.176 a	.115 ab	14.58 d-q	1.56 a-g
July 10	C	13.73 b	20.04 gh	.770 a	.300 ab	10.47 a-m	2.55 k-q
	E	15.73 b	22.53 g-j	1.047 ab	.413 ab	16.00 f-q	2.54 k-q
	P	13.63 b	18.67 g	.720 a	.297 ab	11.43 a-n	2.49 j-q
July 24	C	31.27 fg	29.03 mn	3.170 abc	1.017 a-d	13.73 b-o	3.12 p-u
	E	28.20 def	27.43 k-n	4.173 abc	0.950 abc	18.30 i-q	4.44 xy
	P	28.94 efg	28.53 lmn	3.733 abc	1.387 bcd	16.07 g-q	2.69 l-r
August 13	C	59.13 k	42.60 pqr	18.073 e	4.020 fg	24.27 o-r	4.53 xyz
	E	40.29 h	39.73 p	15.897 e	3.047 ef	23.80 n-r	5.22 z
	P	56.87 k	45.11 r	17.657 e	4.993 gh	22.91 m-r	3.55 t-w

x/ C - Chemung; E - Emerald; P - Penngift.

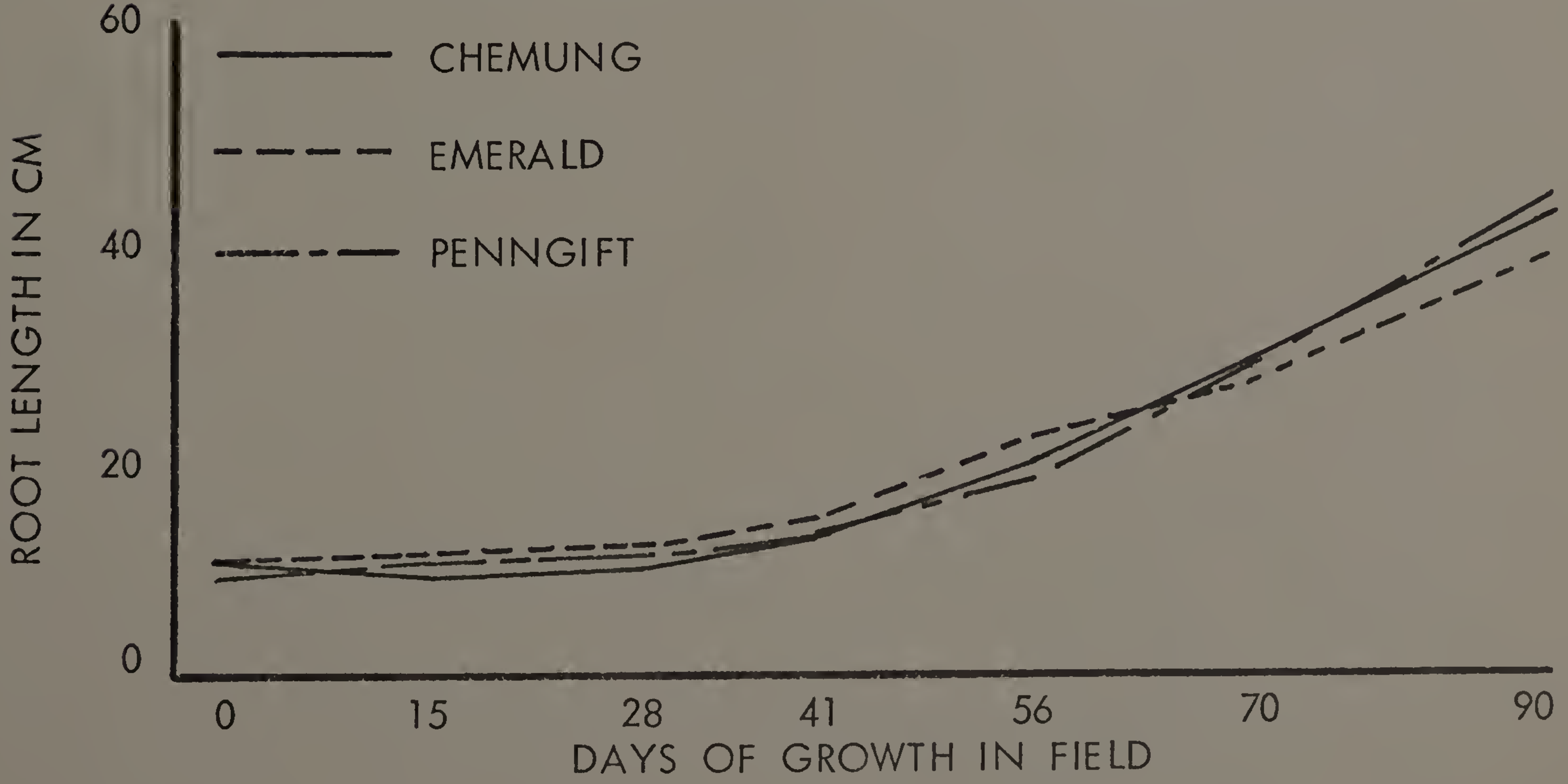
y/ Means in each column followed by a letter in common are not statistically significant at the 5% level according to the Duncan's New Multiple Range Test.

FIGURE 17

A. AVERAGE SHOOT HEIGHT IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



B. AVERAGE ROOT LENGTH IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



longer root length of Penngift and the difference in root length between Emerald and Chemung was not significant (Table 13 and Figure 17 B).

Shoot Dry Weight Production. Shoot dry weight production increased very slowly during the first ten weeks of growth, from .014 grams/plant to 3.7 grams/plant. A rapid increase during the last three weeks resulted in a final shoot dry weight of 17.2 grams/plant. This yield was the lowest and was statistically significant from the shoot dry matter production of plants in Series I and III (Table 11 and Figure 13 A).

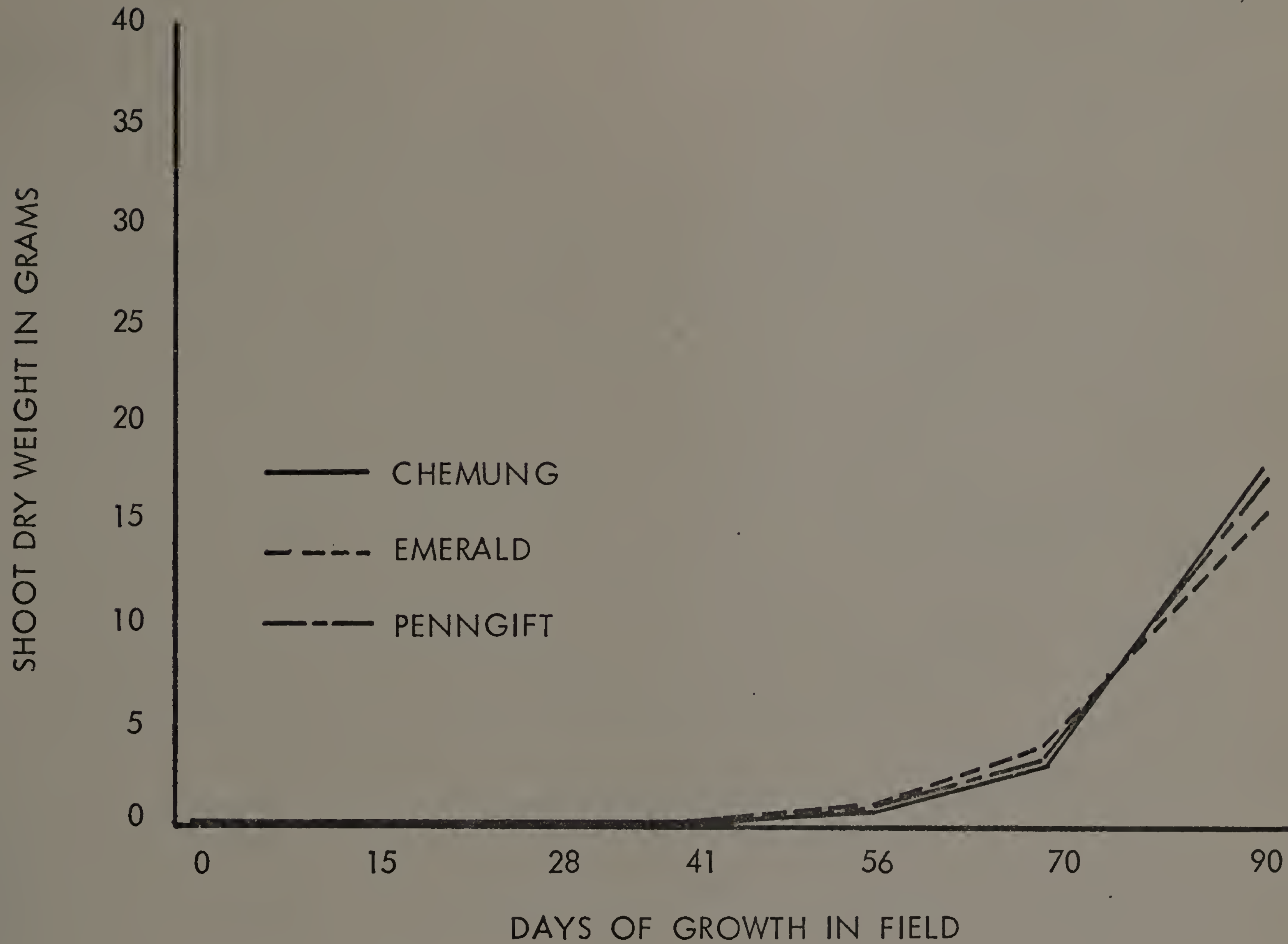
Throughout the entire 90 day growth period there were no statistical differences in shoot dry weight production between the three varieties. Emerald, however, did produce the least shoot weight at the last harvest (Table 13 and Figure 18 A).

Root Dry Weight Production. Throughout the first ten weeks of this growth period, root dry weight production was slightly greater than that of plants in the first series. Final root dry weight of plants in this series averaged 4.0 grams/plant. The rate of increase of root dry weight and the final yield were the lowest of the three growth periods (Table 11 and Figure 13 B).

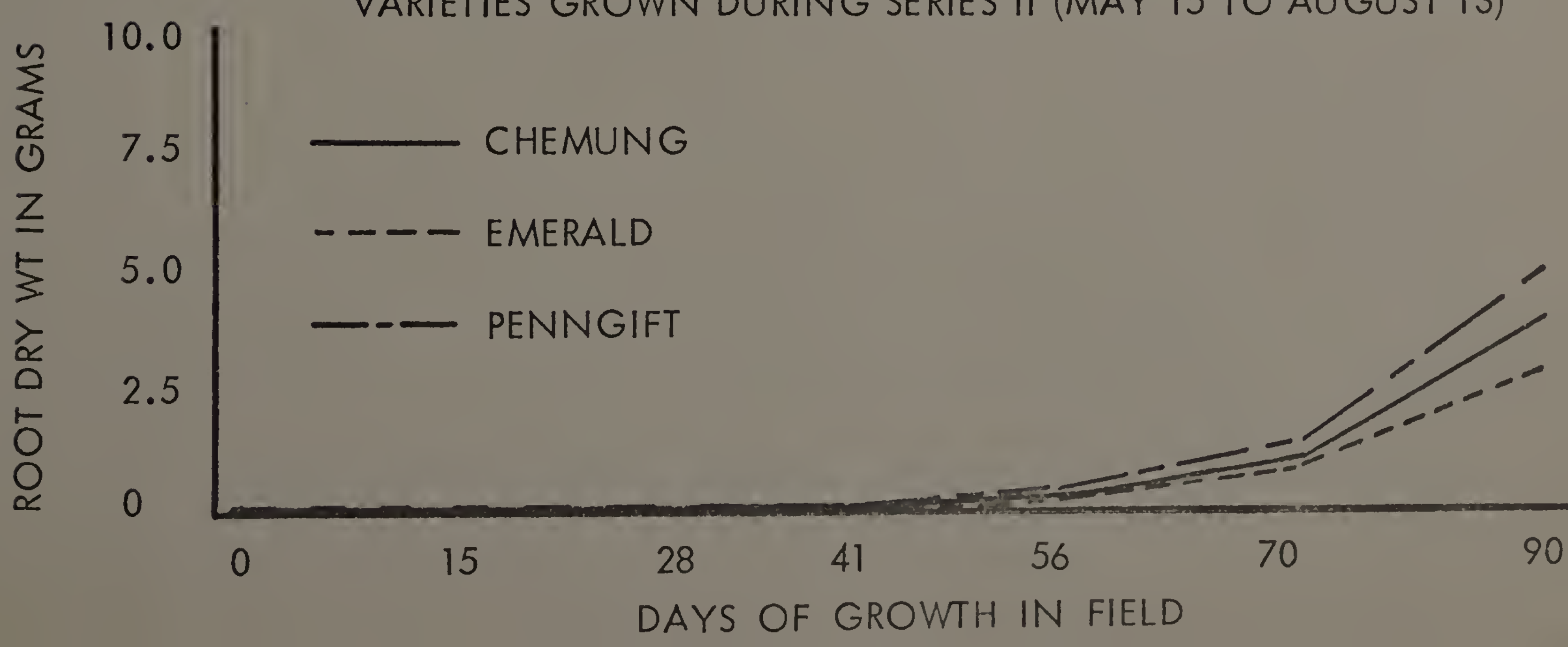
There were no significant differences in root dry weight production between the three varieties during the first 56 days of growth, but in the last five weeks Penngift produced the highest root dry weight which was statistically significant from the root dry weight of the other varieties at the 6th and 7th harvests (Table 13 and Figure 18 B).

FIGURE 18

A. AVERAGE SHOOT DRY WEIGHT IN GRAMS OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



B. AVERAGE ROOT DRY WEIGHT IN GRAMS OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



<u>Nodule Number</u>. The average number of nodules per plant (all varieties) at time of transplanting was 2.2. Nodule production steadily increased for six weeks to a high of 17.1 nodules/plant after which a slight decline in nodule number to 12.6/plant was noticed. Nodule production increased to a final count of 23.7/plant during the last five weeks of plant growth (Table 11 and Figure 15 A).

Throughout the growth period, the number of nodules produced by Chemung and Penngift were approximately the same at each harvest. With the exception of the last harvest Emerald produced slightly more nodules/plant at each harvest, but this greater nodule production was not statistically significant from the other varieties at all seven harvest dates (Table 13 and Figure 19 A).

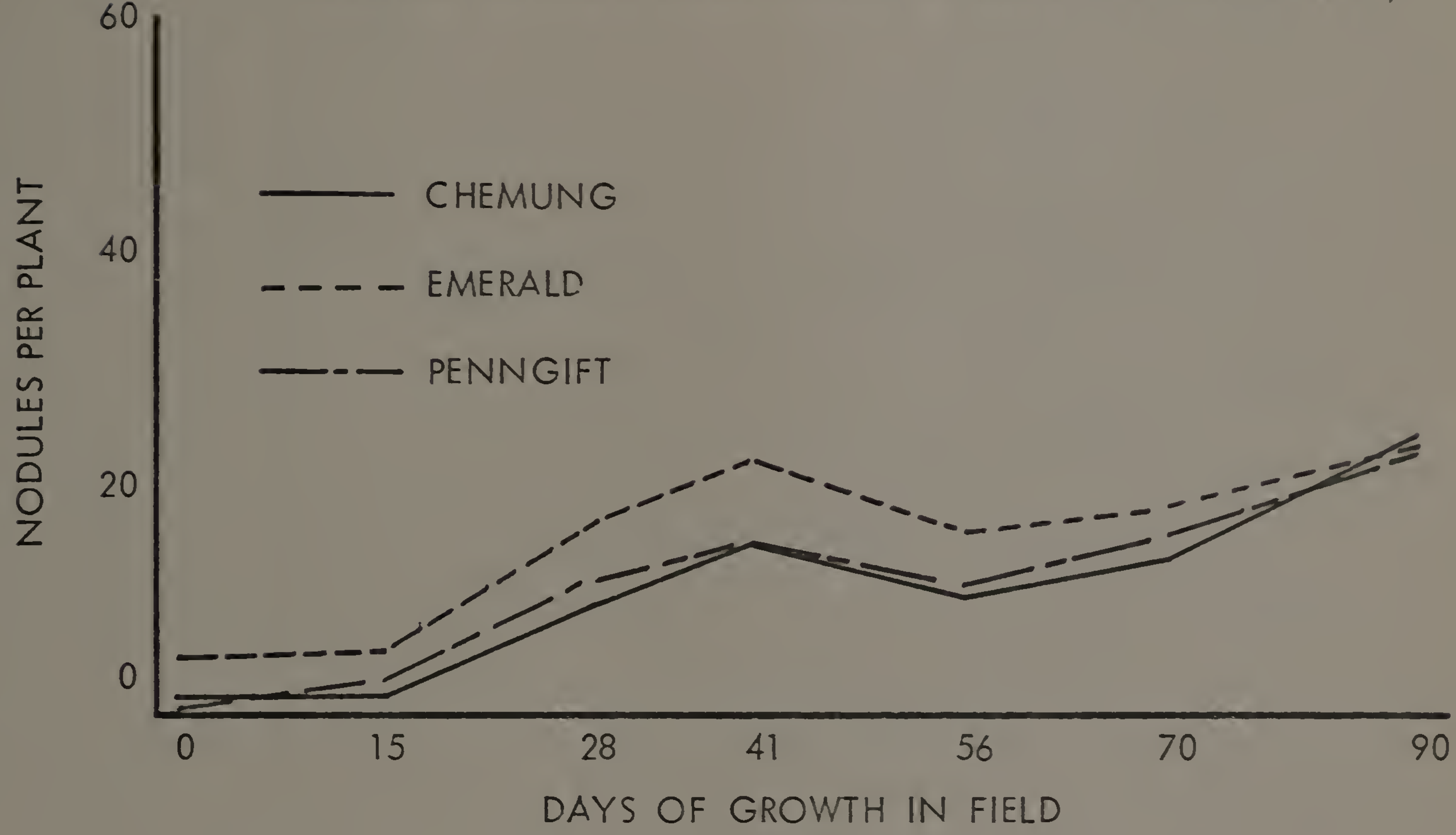
<u>Shoot/Root Ratio</u>. After an initial decrease during the first two weeks of growth, the shoot/root ratio steadily increased from a low of 1.15 to 4.44 by the end of the growth period (Table 11 and Figure 15 A).

From the second harvest to the fifth the shoot/root ratio for all varieties were nearly identical, but from the fifth harvest to the last these ratios separated into three distinct trends.

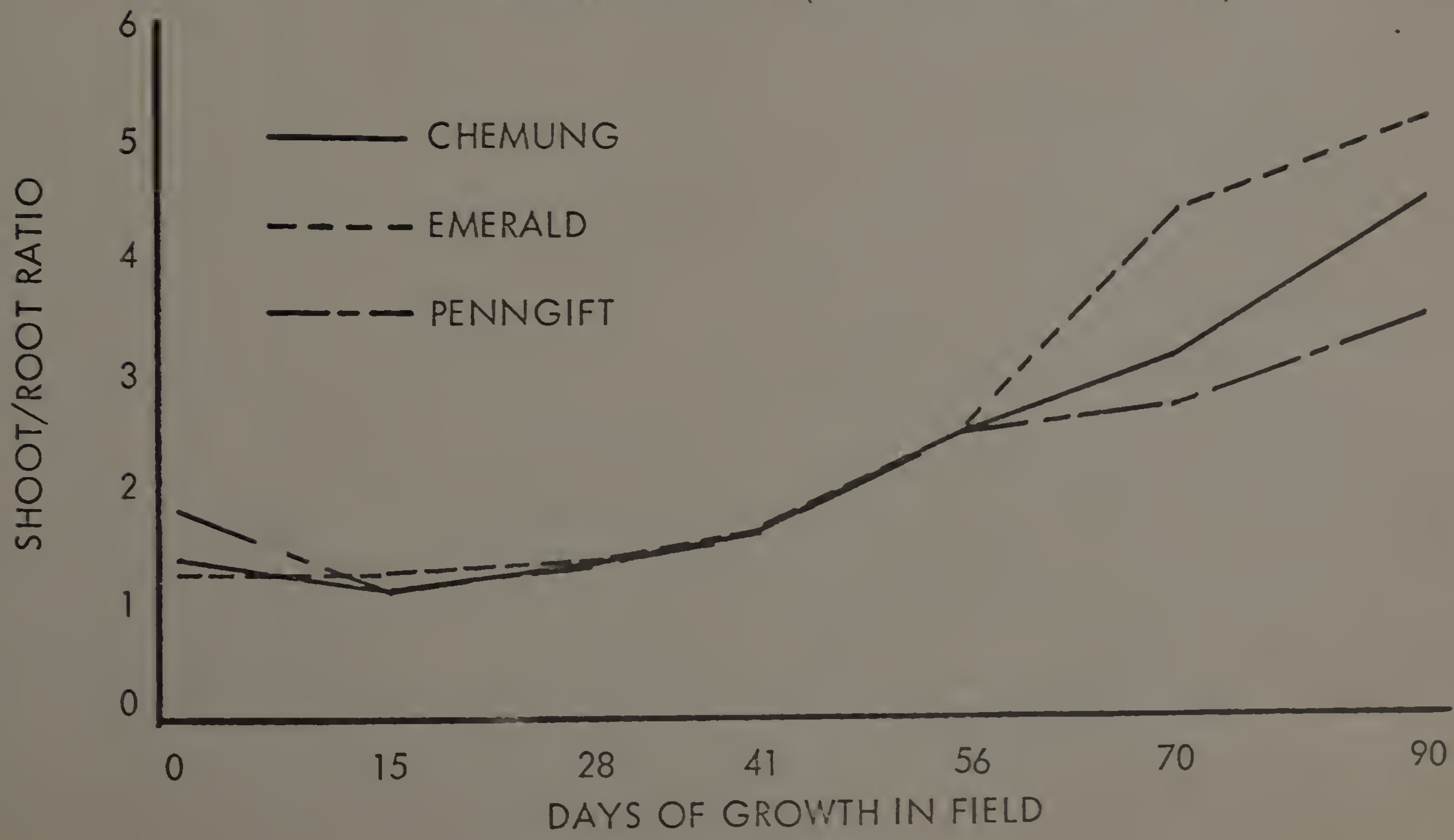
The shoot/root ratio for Emerald was significantly higher than that of the two other varieties at both the 6th and 7th harvest and the low ratio of Penngift was statistically significant from that of Chemung at the last harvest (Table 13 and Figure 19 B).

FIGURE 19

A. AVERAGE NODULE NUMBER PER PLANT OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



B. SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES II (MAY 15 TO AUGUST 13)



III. Series III (June 9 to September 5)

Environmental Conditions

Photoperiod. The third planting was made on June 9 at a photoperiod of 18 hours and 1 minute. The maximum photoperiod of the year, June 22, came 14 days after the start of this series. At the termination of the experiment the photoperiod was 14 hours and 49 minutes (Figure 8).

Temperature. The average monthly temperatures for June, July and August have already been described. The temperature for September was 1.4° F above normal (Tables 9, 10 and Figure 9 C).

Rainfall. Rainfall was below normal during the first seven weeks of plant growth. During the remainder of this growth period a total of 10.4 inches of rain fell (9.5 inches from July 28 to August 4) (Table 10 and Figure 10).

Shoot Height. The increase in shoot height of plants grown during the first ten weeks of the third series was greater than that of plants of the same age in the other two series. After the tenth week the rate of increase declined and the final shoot height was 52.2 cm (Table 11 and Figure 11 A). This was not statistically significant from the shoot height of plants in the second series but was for the shoot height in the first series.

Shoot height of all varieties was about the same for the first four weeks in the field, after which it increased rapidly. Chemung produced the tallestplants and Penngift the shortest throughout the remainder of the growth period. This difference in shoot height between these two varieties was statistically significant during the last five weeks of growth (Table 14 and Figure 20 A).

TABLE 14

AVERAGE LENGTH AND WEIGHT OF SHOOTS AND ROOTS, NUMBER OF NODULES/ PLANT AND SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES HARVESTED SEVEN TIMES DURING SERIES III (JUNE 9 - SEPTEMBER 5)

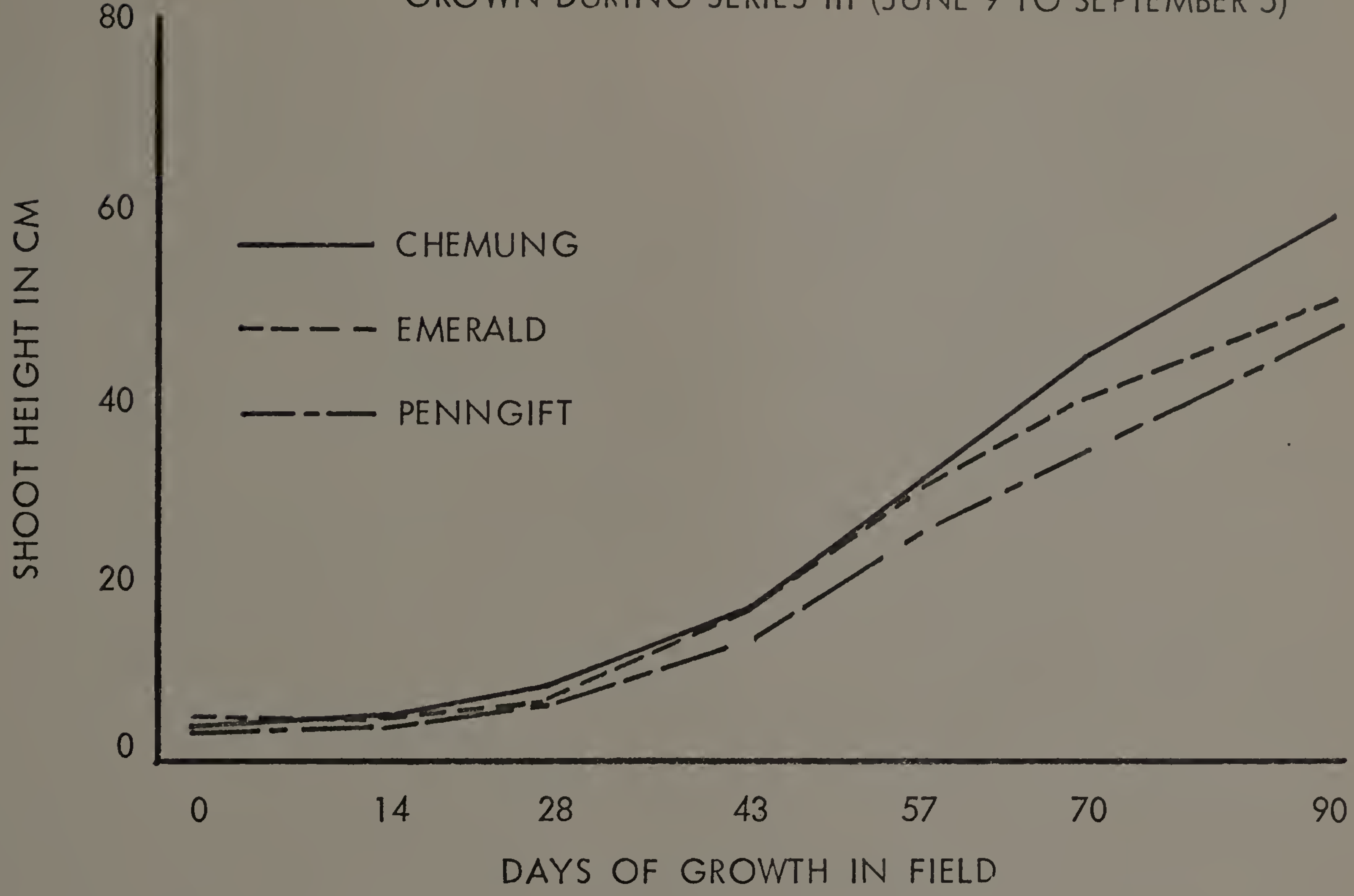
Harvest Date 1969	Var.	Shoot Height cm	Root Length cm	Shoot dry Weight g	Root dry Weight g	Nodule Number	Shoot/Root Ratio
June 9	C x/	3.90 a y/	10.43 a-f	.019 a	.010 a	1.36 abc	1.82 b-j
	E	4.80 a	11.32 a-f	.028 a	.011 a	2.33 a-e	2.48 j-q
	P	3.16 a	9.79 a-d	.013 a	.005 a	0.53 a	2.50 k-q
June 23	C	4.60 a	11.23 a-f	.030 a	.021 a	4.04 a-g	1.46 a-f
	E	4.92 a	11.75 a-f	.037 a	.023 a	4.38 a-g	1.66 a-h
	P	3.66 a	11.00 a-f	.023 a	.017 a	4.22 a-g	1.37 a-d
July 7	C	7.63 a	14.36 ef	.168 a	.058 ab	14.04 c-p	2.89 m-t
	E	6.72 a	14.44 ef	.166 a	.054 ab	12.69 a-o	3.18 q-v
	P	5.86 a	14.92 f	.098 a	.041 ab	10.42 a-m	2.43 i-q
July 22	C	16.65 b	24.70 i-l	.897 ab	.326 ab	17.87 i-q	2.76 m-s
	E	16.55 b	23.80 h-k	1.076 ab	.269 ab	16.10 g-q	4.01 wx
	P	13.35 b	24.12 h-k	.588 a	.255 ab	11.93 a-o	2.28 g-o
Aug. 5	C	29.95 fg	30.98 no	3.783 abc	1.083 a-d	18.69 j-q	3.48 s-w
	E	29.44 efg	24.49 i-l	5.100 abc	.947 abc	11.89 a-o	5.35 xyz
	P	24.53 cde	27.69 k-n	2.777 ab	.767 ab	11.64 a-o	3.62 uvw
Aug. 18	C	43.60 hi	40.54 pq	7.670 cd	2.260 de	26.56 pqr	3.41 r-w
	E	39.02 h	39.49 p	9.683 d	2.040 cde	18.67 j-q	4.76 yz
	P	33.74 g	34.38 o	5.830 bcd	1.893 cde	20.11 k-q	3.02 o-u
Sept. 5	C	58.80 k	52.05 s	23.073 f	9.900 j	55.55 t	2.39 h-p
	E	50.31 j	49.73 s	27.143 f	7.537 i	55.18 t	3.62 uvw
	P	47.47 ij	44.07 qr	16.700 e	7.247 i	33.07 rs	2.30 g-o

x/ C - Chemung; E - Emerald; P - Penngift.

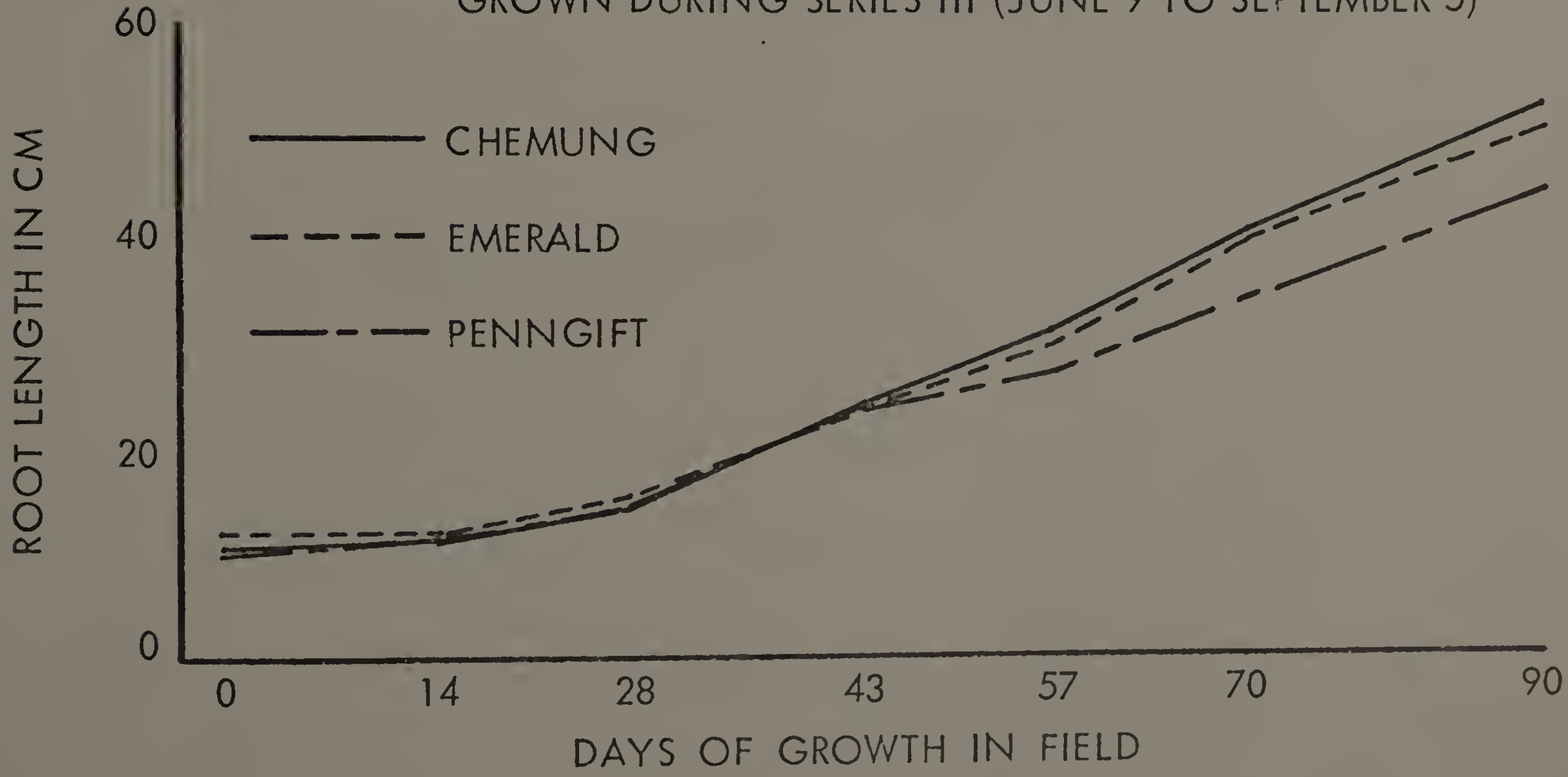
y/ Means in each column followed by a letter in common are not statistically significant at the 5% level according to the Duncan's New Multiple Range Test.

FIGURE 20

A. AVERAGE SHOOT HEIGHT IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



B. AVERAGE ROOT LENGTH IN CM OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



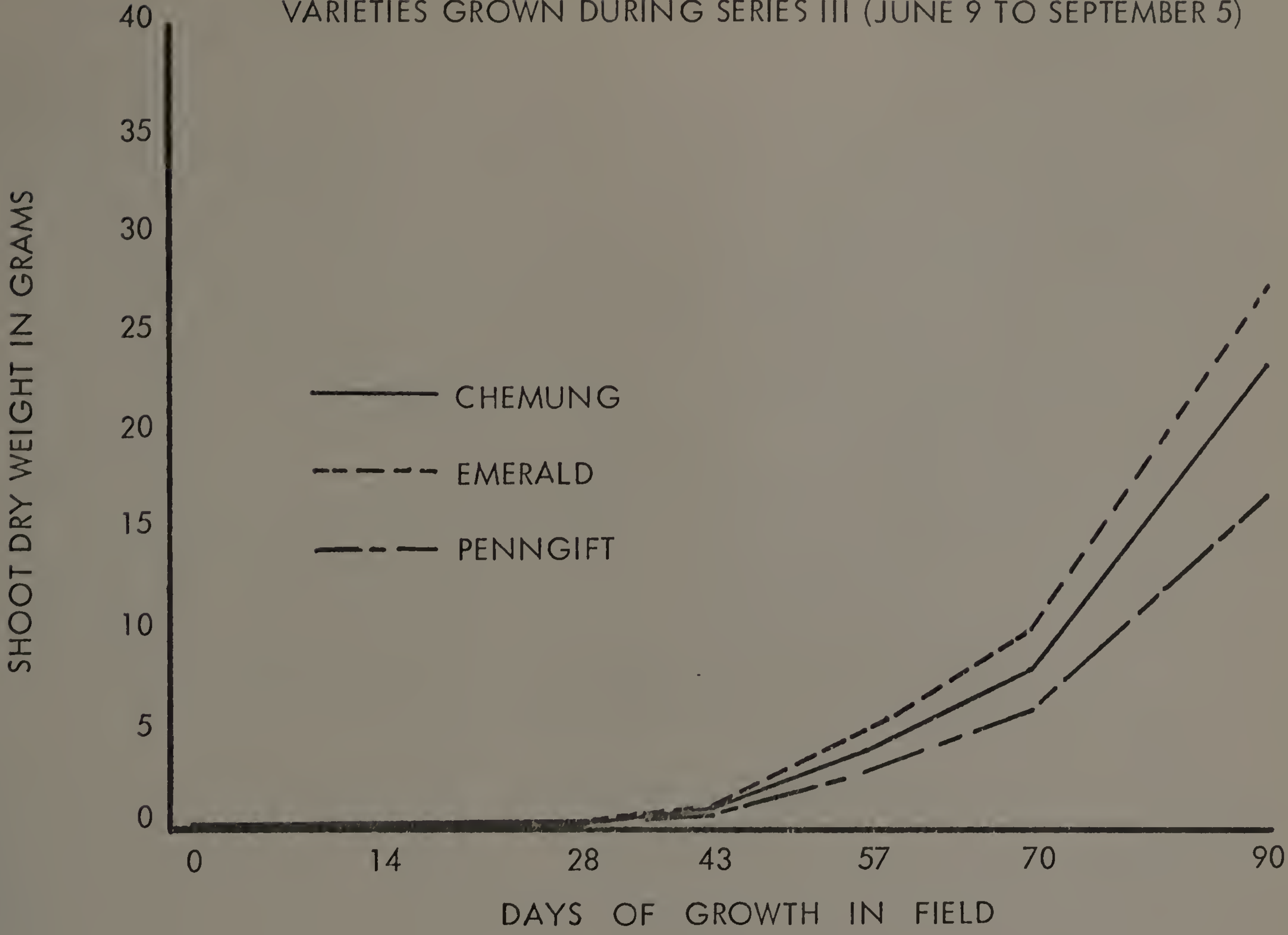
Root Length. Root length increased steadily from the time the plants were transplanted on June 9. The final average root length was 49.0 cm/plant (Table 11 and Figure 11 B). Up to the fourth harvest (after 43 days of growth in the field) the root length of all varieties was approximately the same. Throughout the rest of the growth period Chemung produced the longest roots and Penngift the shortest, but the difference was only statistically significant at the sixth and seventh harvests (Table 14 and Figure 20 B).

Shoot Dry Weight Production. Shoot dry weight production increased very rapidly during the first ten weeks of plant growth. During this period more shoot dry weight was produced than was produced by plants in the other growth periods. The final shoot dry weight of plants in this series averaged 22.3 grams/plant which was statistically significant from the shoot weight of plants in the other two series (Table 11 and Figure 13 A).

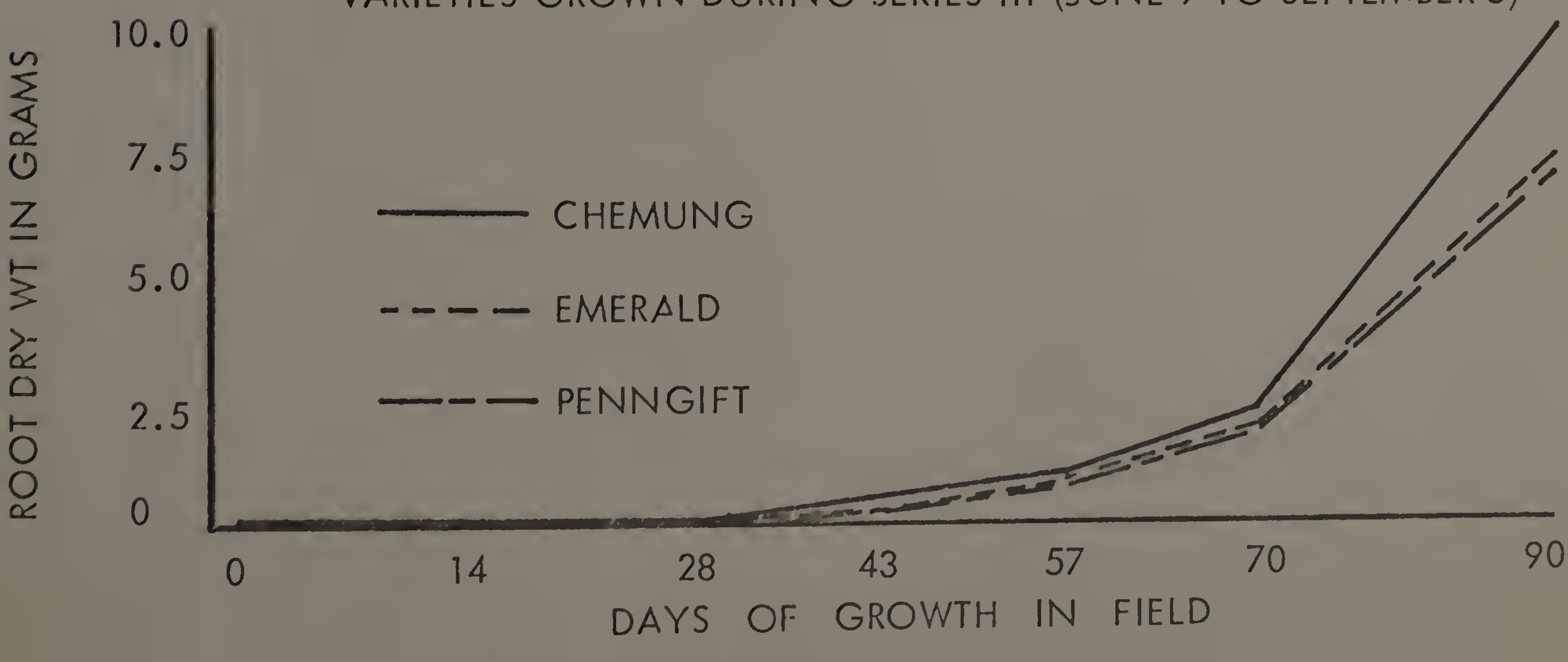
After six weeks of growth in the field varietal differences became more pronounced. Penngift produced the smallest amount of shoot dry weight when compared to the other varieties, but this difference was only statistically significant at the last harvest. Throughout the remainder of the growth period Emerald produced the greatest amount of shoot dry weight but this was not statistically significant from the shoot production of Chemung (Table 14 and Figure 21 A).

FIGURE 21

A. AVERAGE SHOOT DRY WEIGHT IN GRAMS OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



B. AVERAGE ROOT DRY WEIGHT IN GRAMS OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



Root Dry Weight Production. Compared to root dry weight production in Series I and II, plants in Series III produced the greatest amount of root dry weight at each harvest throughout the growth period. Final root dry weight averaged 8.23 grams/plant. This yield was statistically greater than the root weight of plants in the other series. The period of most rapid increase was from August 18 (6th harvest) to the last harvest date (September 5) (Table 11 and Figure 13 B).

Root dry weight production of Emerald and Penngift was approximately the same throughout the growth period. Chemung produced the same yield of root dry weight as the other varieties until the sixth harvest, after which it produced significantly more (Table 14 and Figure 21 B).

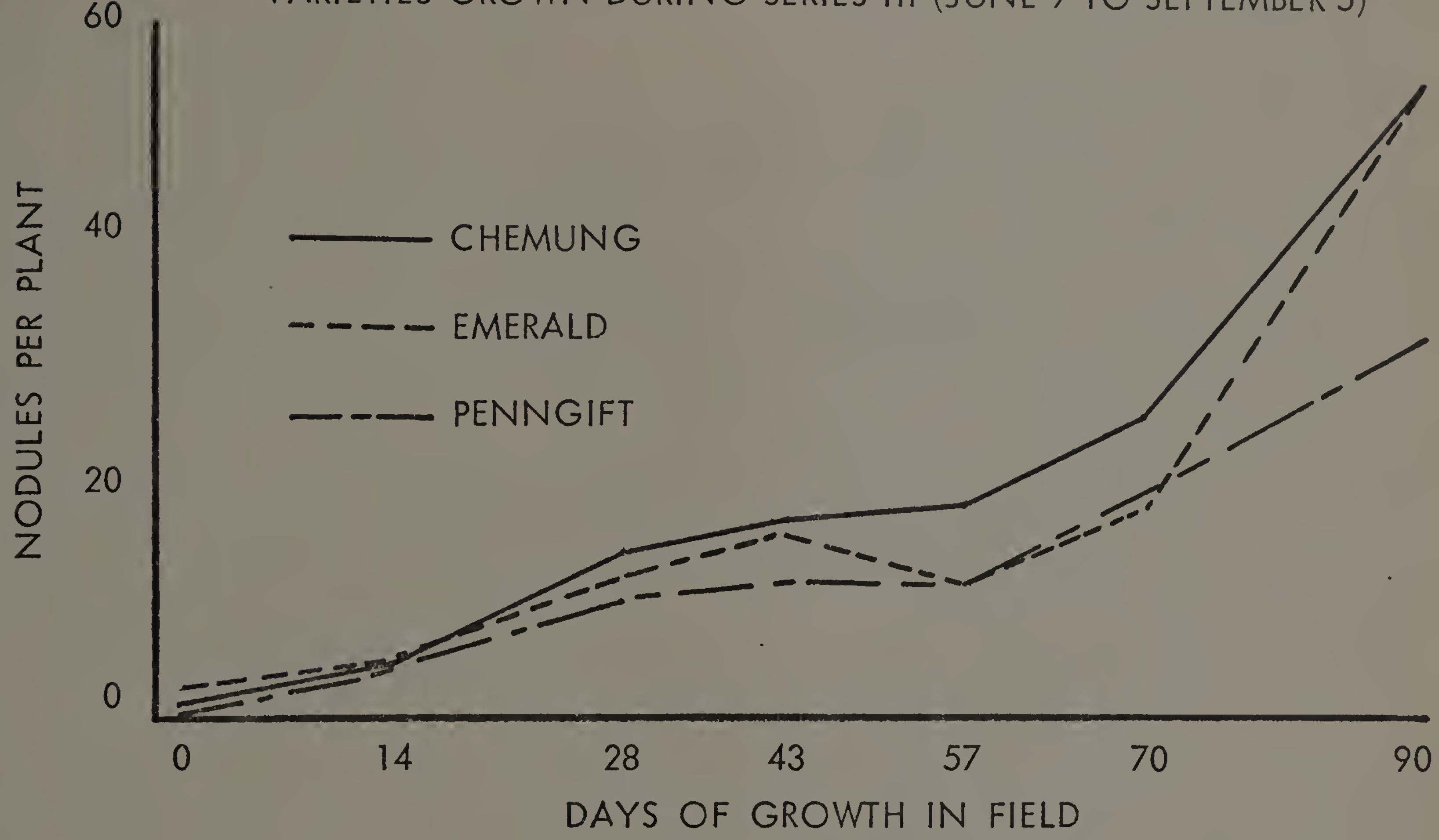
Nodule Number. With the exception of a decline in the rate of nodule production during the eighth and ninth weeks of growth, the number of nodules produced per plant increased at a constant rate. Final count averaged 47.93 nodules per plant. This was highly significant from nodule production on plants in Series I and II (Table 11 and Figure 5 A).

Penngift had fewer nodules per plant and was significantly different from the other two varieties at the last harvest. Chemung produced the largest number of nodules per plant throughout the entire growth period (Table 14 and Figure 22 A).

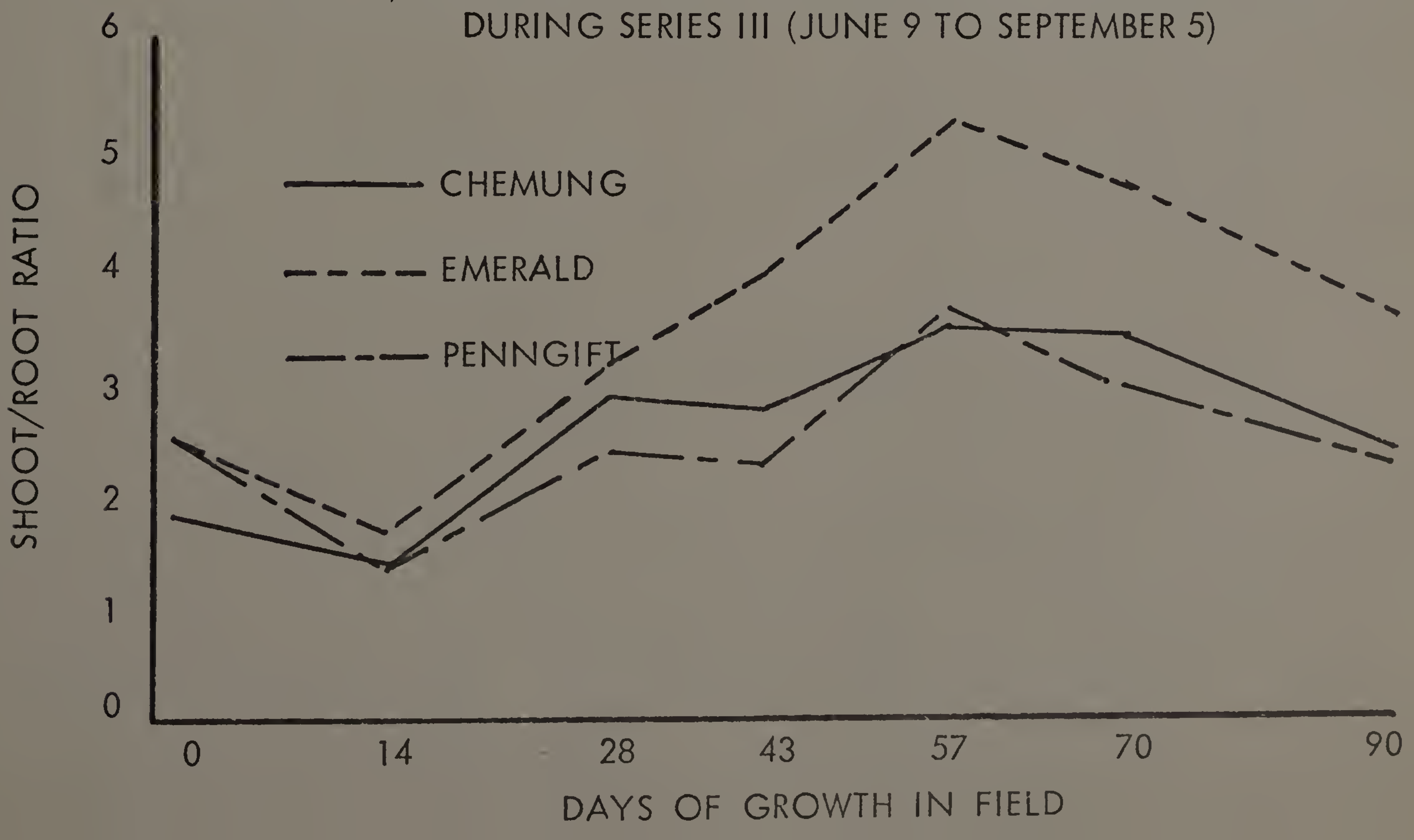
Shoot/Root Ratio. The shoot/root ratio, after an initial decrease during the first two weeks of growth, increased steadily. A slight decline in the rate of increase of the ratio occurred at the fourth harvest but then increased to a high

FIGURE 22

A. AVERAGE NODULE NUMBER PER PLANT OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



B. SHOOT/ROOT RATIO OF THREE CROWNVETCH VARIETIES GROWN DURING SERIES III (JUNE 9 TO SEPTEMBER 5)



of 4.15 at the fifth harvest. From that harvest to the end of the growth period shoot/root ratio declined to a low of 2.77 (Table 11 and Figure 15 A).

The varieties Chemung and Penngift had the two lowest ratios and were not significantly different from each other. Emerald had the highest ratio which was statistically significant from the other varieties throughout most of the growth period (Table 14 and Figure 22 B).

C. Discussion

Shoot Height. One of the growth characteristics of long-day plants grown under long-day conditions is a rapid increase in shoot height. The relatively slow increase in height of crownvetch shoots during the first six weeks of growth in Series I can possibly be attributed to several factors; one being the shorter photoperiods that occur during that time of the season and the other, the low seasonal temperatures that the plants were subjected to during the first half of this growth period. Suboptimal levels of both of these environmental factors, as occurred in Series I, will not result in maximum plant growth. As plant growth proceeded during Series I, crownvetch responded to the seasonal increase in photoperiod as indicated by the rapid increase in shoot height between July 7 and July 28 harvests. This response to photoperiod agrees with work done by Carlson (18) on crownvetch.

This acceleration in shoot height occurred approximately 15-19 days after the day with the longest calculated photoperiod (June 22) and was evident in plants in all three series. Since the crownvetch plants growing at this time were planted on three different dates, and as a result vary in stages of maturity, it seems likely that this rapid increase in shoot height was due to the increase in the length of the seasonal photoperiod.

Since the data of the July 7 harvest did not show a large change in shoot growth, but that of the July 28 harvest did (Table 11), it would seem that there was a two to three week time lapse from the time at or near the longest day to when the increase in shoot height was apparent. This indicates that even though a plant is highly receptive to an environmental stimulus it may still require an adequate period of time for growth and development in order for the response to that stimulus to become evident.

Shoot height of plants grown during the first ten weeks of Series I and II was approximately the same. Plants in Series III, however, produced taller shoots during that time period. The reason for this may be the longer photoperiod and higher temperatures these plants (Series III) were subjected to during the first ten weeks of growth in comparison to plants in Series I and II.

At final harvest (after 90 days growth) the greater shoot height of plants in Series I can be attributed to the increase in duration of the photoperiod as compared to the shorter photoperiods at the final harvests in Series II and III.

Plants in Series II and III were equal in shoot length after 90 days growth in the field. The longer photoperiod at final harvest in Series II (16 hours and 9 minutes) did not result in taller plants than those in Series III (photoperiod = 14 hours and 49 minutes), possibly because of the excessive rainfall that occurred since the preceding harvest. This caused a saturated soil condition which may have limited the growth of crownvetch during this period.

In contrast to the moisture conditions toward the end of the growth period in Series II, plants in Series III only received .5 inch of rain during the last 26 days of growth in the field. This lack of water together with the seasonal decrease in photoperiod and night temperatures may have been factors responsible for the low final shoot height in Series III.

With the exception of the last three weeks of growth in Series I and II and four weeks in Series III, there did not appear to be any large differences in shoot height between varieties during the growth periods. By the end of each series, however, Chemung had produced the tallest plants while Emerald or Penngift produced the shortest. This varietal characteristic of Chemung to produce taller plants may be of significant value when choosing a variety of crownvetch for use in erosion control.

Root Length. In all series the root length of crownvetch increased as plants attained maturity. The slight decline in the rate of increase of root length in Series I (near July 7) is unexplained. In Series II the reduction in the rate of increase in root length, apparent at the sixth harvext (July 24), could have been caused by the same environmental factors (shorter photoperiods and excessive rainfall) that may be responsible for similar results in shoot dry matter production (Table 11, see discussion on Shoot Dry Matter Production).

The root length of plants in Series III was consistantly larger than for plants of the same age grown in Series I and II. This greater root length lasted only ten weeks after which the rate of increase declined. The reasons for this could be that during the first ten weeks of growth in Series III the daily night air temperatures must have been high enough to sustain rapid root growth, even though the natural photoperiod was decreasing in duration. The low final root length reflects the result of decreasing night temperatures during the last three weeks of growth in the field.

In most instances there were only small differences in root length between varieties at each harvest date and series in which plants were grown. Even though Penngift produced the shortest roots during the last 30 days of growth in Series I and III, the differences in root length between this and the other varieties were small and are not thought to be critical when considering which specific variety of crownvetch to use.

Shoot Dry Matter Production. The rapid rise in shoot dry matter production of crownvetch which coincided with its increase in shoot height occurred in Series I only.

Plants of all three series were grown in the field for approximately 70 days before this rapid rise in the rate of increase of shoot weight was noticed. Due to the variable environmental conditions leading up to the 70th day of growth, in each particular series, it would seem that the influence of the local environment could be excluded as a dominate factor in this rapid increase of shoot growth.

The acceleration of shoot dry matter production at various times (July 7, July 24 and August 18 for Series I, II and III, respectively) suggests that the crownvetch plant may have had to reach a particular stage of maturity before significant increases in shoot growth could occur.

Even though shoot weight yields at the last harvest were greatest for plants in Series I, plants in Series III produced larger yields during the first 70 days of growth when compared to the yield of plants of the same age in Series I and II. These plants (Series III) were exposed to warmer air temperature and longer photoperiods during this growth period which may account for the increase in the rate of growth. As the seasonal photoperiod decreased, toward the end of Series III, the crownvetch responded by producing somewhat less shoot growth than had plants of the same age in Series I grown under longer photoperiods. This photoperiodic response of crownvetch to the duration of photoperiod is typical for long-day legumes.

The low shoot yields of plants in Series II during the last three weeks of growth in the field could have been due in part to the decreasing seasonal photoperiod, but the major factor resulting in poor growth may have been the excessive rainfall that was received during that growth period.

Crownvetch cannot tolerate wet soil conditions for an extended length of time without showing some signs of adverse effects, such as yellowing of the foliage and limited root growth (92). According to weather data for the last 21 days of this growth period (Series II) the crownvetch plants received 9.9 inches of rain. This excessive rainfall may have had some adverse effects on root growth during a period in which the plants would be most actively growing, subsequently, shoot dry matter production, shoot height and root length could also have been affected.

Plants in Series III were larger when compared to plants of the same age in Series I and II (up to 70 days growth). The earlier transplanting of crownvetch, April 29, compared to May 15 and June 9 (for Series I, II and III, respectively) enabled plants in Series I to accumulate more growth. In practical application it would appear that the earlier crownvetch was transplanted the more effective it would be in controlling erosion.

Root Dry Matter Production. Although crownvetch root yields were relatively small during the first ten weeks of growth in Series I and II, visual observations revealed that roots were well branched and had many root hairs.

The low root yield at the last harvest of plants in Series II may have been caused by the excess rainfall that also seemed to have an effect on shoot production (Table 11, see discussion on Shoot Dry Matter Production).

Crownvetch roots in Series III, from the third week of growth to final harvest, were very dense and weighed more than roots of the same age in other series despite the fact that there was inadequate rainfall (.5 inch) during the last 26 days of growth. The greater root production of plants in Series III may have been the result of carbohydrate accumulation that occurs in the roots of some species of plants during a period of decreasing temperatures and decreasing natural photoperiods (such as those that occurred near or at the end of Series III). The increase in root dry matter production and its relationship to decreasing photoperiods has also been reported by Carlson et al. (17) and Coffindaffer et al. (19) in alfalfa, McKee (54) with birdsfoot trefoil and Kasperbauer (44) with biennial sweetclover.

The crownvetch in Series III produced the largest root systems when compared to plants of the same age in Series I and II, but plants in Series I had the largest total root growth because of the longer growing period in the field. A transplanting of crownvetch as early as possible in the season would probably result in greater overall growth when compared to the growth of plants transplanted at a later date.

There was very little difference in root dry matter production between varieties during the first 70 days of growth in all series. During the last three weeks of growth in Series I and III Chemung and Emerald were more productive than Penngift, whereas Penngift was the most productive variety in Series II. This inconsistency in root production between varieties may be explained by the fact that near the end of Series II (last 16 days) 9.9 inches of rain fell which may have had a detrimental effect on the overall growth of crownvetch. Of the three varieties Penngift appeared to acclimate itself to the suboptimal soil moisture conditions more successfully than did Chemung or Emerald being able to produce longer roots and more shoot and root dry matter. This only occurred in Series II.

During periods of normal or below normal rainfall (last four weeks of Series III) Chemung and Emerald were the most productive. The root systems of these varieties, especially Chemung, appeared to be more dense and weighed more than those of Penngift. These varieties, Chemung and Emerald, may be more effective in helping to reduce the effects of erosion on highway slopes by being able to produce more roots to hold the soil firmly in place.

<u>Nodule Number</u>. There were small differences in nodule number between plants in Series I, II and III during the first two weeks of growth (Table 1). The low nodule production may be due to low temperature. According to Barrios *et al*. (4), Pate (66) and Dart (24), the optimum temperature for root hair infection in 25°C (77°F) with some infection occuring at temperatures as low as 17°C (62.5°F).

The average daily mean temperatures in this study were less than 17°C for the first two weeks of growth in Series I but not in Series II and III where low nodule yields were also recorded (Table 9). A more reasonable explanation of this low nodule production could be the immaturity of the crownvetch plant and also injury to roots during transplanting. At this stage of growth, root hair production may be low and so the number of available infection sites would be limited.

One of the requirements necessary for nodulation and nitrogen fixation to occur is the presence of an adequate carbohydrate/nitrogen ratio in the plant. If the nitrogen level is excessive, increased vegetative growth will occur which may cause a low carbohydrate level which will result in inhibition of nodulation and nitrogen fixation. Also, an excessively high carbohydrate level may inhibit nodulation and nitrogen fixation by the plant (85).

The decrease in nodule production of plants in Series I, II and III (Figure 15) occurring just prior to the acceleration of shoot and root growth could have been caused by a decrease in the carbohydrates available to the rhizobium. The major portion of the available carbohydrates were probably used for the increase in vegetative growth.

The rhizobium depend on carbohydrate production of the host plant for existance and a decrease in the supply of carbohydrates to the nodules may result in reduced nodulation, decreased nitrogen fixation of nodules present, and possibly even the degeneration of some existing nodules.

The increase in nodule number that occurred during the last three to five weeks of growth in all series could have been due to an increase in the carbohydrate level in the plant and the increase in the number of infection sites (root hairs).

The low nodule count at final harvest in Series II reflects the effects of excessive rainfall on nodulation. Whether or not this is a direct effect on rhizobial growth and infection is not known but it may have had an indirect effect by limiting root growth. The low root production at this time indicates that this may have been the cause (Table 1). The decrease in nodule number at the fifth harvest in Series III may have been caused by excess moisture.

The large yield of nodules at the last harvest in Series III may have been the indirect result of decreasing photoperiods. During this time root growth increased and a decrease in the rate of shoot production was noted. This may have provided a larger number of infection sites and more carbohydrates to the rhizobium, which would result in greater nodulation.

There was very little difference in nodule production between varieties in Series II, possibly because of the excess rainfall. In Series I Emerald produced the most nodules and was about the same in production as Chemung in Series III.

Although there isn't a clear-cut picture of varietal preference with respect to nodule production, it appears that either Emerald or Chemung may be more suitable for use on relatively infertile soils.

Shoot/Root Ratio. In considering a plant species for use in erosion control many factors have to be evaluated. A few of these are: fertility requirements of the plant; site and soil adaptation; characteristics of the vegetative growth; and the shoot/root ratio.

The shoot/root ratio is the amount of shoot production in relation to root growth. A plant having a high proportion of root growth to shoot growth will have a low shoot/root ratio. This low ratio indicates that the plant may be suitable for use in erosion control (30).

The decrease in the shoot/root ratio (for plants in all series) during the first two to three weeks of growth was probably due to more carbohydrates being utilized for root growth than shoot growth at this time.

The increasing shoot/root ratio of plants in Series I, II and during the first 70 days of Series III indicate a greater rate of shoot growth than root growth. The decreasing ratios near the termination of Series III may reflect the effects of changing environmental conditions (decreasing photoperiods) favorable to the increase in root growth.

The variety of crownvetch that is able to produce the lowest shoot/root ratio would probably be the most desirable to use in erosion control. Foote and Johnson (30) had reported that Penngift had the lowest ratio of five varieties tested. In this study it was found that there was little difference in the shoot/root ratio between Chemung and Penngift. It should be noted, however, that while the shoot/root ratio of Penngift was low, so was the shoot and root dry matter production that comprised this ratio.

A COMPARISON OF GROWTH TRENDS IN GROWTH CHAMBER AND FIELD STUDIES

Crownvetch grown in growth chambers was subjected to the controlled environmental factors of photoperiod, temperature, and moisture. A change in any one of these factors could and often did result in a noticeable variation in the rate of growth of the plant. This variation in the rate of growth was difficult to identify in the field study because the continually changing light, temperature, and moisture conditions interacted to form a growth environment that changed from day to day, even hourly. Even though the environmental conditions varied in the two studies the growth of some plant characteristics did exhibit similar trends.

In both field and chamber studies, the length of the top growth and shoot and root dry matter production increased as the temperature and the duration of the photoperiod increased. Although there was little or no increase in shoot height between the plants grown in the 9- and 12-hour photoperiods (in the chambers), the 15-hour photoperiod had a significant influence on shoot height, as did the long-day photoperiods around June 22.

Of the above mentioned plant characteristics the only dissimilarity that occurred was in root production between plants grown in the growth chambers and in the field. A large increase in root weight was apparent in plants grown in Series III in the field during the last three weeks of growth. This can be explained partly by the fact that plants in the field were 30 days older than the chamber plants at final harvest. Also, the photoperiod in the chambers remained constant (at 9, 12 or 15 hours), whereas the natural photoperiod in Series III increased and then decreased. This decrease in photoperiod may have limited shoot production thereby increasing the accumulation of carbohydrates in the roots.

A comparison of root production in these two studies showed that after 60 days growth (length of the growing period in the chambers) plants in the growth chambers produced slightly more root growth than did plants grown in the field.

The progressive increase in root length (with increasing temperatures and photoperiods) of field plants was only apparent in the chamber grown plants subjected to increasing temperatures. An increase in the duration of the controlled photoperiod decreased root length. This decrease in root length was not noticed in the field probably because both the photoperiod and temperature increased concurrently and it was difficult to separate the effects of each.

There were no trends in the number of nodules produced on crownvetch plants grown in each of these two studies.

The shoot/root ratio of plants in each study varied widely. The average ratio of plants grown in the chambers rarely went above 1.00 whereas in the field the average ratio was found to be approximately 3.00 (at the end of 60 days growth). This higher ratio indicates a greater increase in top growth to root growth, presumably because the environmental factors of light, non-fluctuating temperatures (other than day and night), and adequate soil moisture conditions were more conducive to plant growth (specifically root production) in the growth chambers than they were during the first 60 days in the field.

SUMMARY AND CONCLUSIONS

The effects of various photoperiods and air temperatures on the growth of three crownvetch varieties were investigated in both a controlled environment and in the field.

In the growth chamber study, due to the juvenility of the plants, no reproductive primordia was initiated, therefore, the critical photoperiod and the day length response group could not be ascertained. However, Carlson (18) has reported that crownvetch is a long-day plant. Observations on the growth of the plant (shoot and root length and dry matter production) in the 9-, 12-, and 15-hour photoperiods indicate that crownvetch may be a long-day plant because it responds in a manner similar to other known long-day plants. The significant increase in shoot and root growth that occurred in plants grown in the two shorter photoperiods and the longest photoperiod indicates that the critical photoperiod may be longer than 12 hours and possibly less than 15 hours in duration.

The effect of long-day photoperiods on the growth of crownvetch was noticeable in plants at various stages of maturity. Crownvetch plants that were subjected to increasing natural photoperiods followed by decreasing natural photoperiods showed an increase in the rate of root growth. This was indicated by a decreasing shoot/root ratio. The reason for this increase was probably due to carbohydrate accumulation in the roots.

An increase in either or both photoperiod and/or temperature resulted in greater shoot and root growth. Nodule production may have been indirectly affected by these environmental conditions which as a result of greater shoot and root growth could have provided the necessary root hairs and carbohydrates needed for increased nodule production.

From the data available, it appears that excessively wet soil conditions do have a detrimental effect on the growth of crownvetch. During and after periods of prolonged rainfall, the rate of increase in shoot and root length and dry matter production declined.

Increasing night temperatures (within the scope of this study) resulted in greater crownvetch growth. The most favorable night temperature for optimum growth was not determined as the rate of growth appeared to be increasing in plants grown at the highest night temperature (18.3°C). To obtain the maximum effects of temperature on the growth of crownvetch, plants may have to be subjected to night temperatures greater than 18.3°C.

The interaction of photoperiod and temperature on the growth of crownvetch in growth chambers indicates that for plants grown in short-day photoperiods, temperatures above 15.6° C have only a minimal effect on shoot and root dry matter production. However, the increase in crownvetch growth due to the influence of night temperatures greater than 15.6° C and 15-hour photoperiods shows the effects of a temperature and photoperiod interaction as the quantities of these factors are increased.

From results obtained throughout the growth period in the chamber and field studies, it is evident that even though all three varieties of crownvetch are suitable for use in controlling erosion, the varieties Chemung and Emerald seem to be more vigorous in growth (as shown by greater shoot and root growth and number of nodules produced) than Penngift and may be more suitable to use when vegetative cover is desired as rapidly as possible.

The field study has shown that plants transplanted early in the spring produced more total growth, when observed at any time during the season, compared to plants transplanted later in the growing season. In practical application it would seem reasonable to assume that crownvetch plants transplanted on Massachusetts roadside slopes as early as possible would produce maximum growth and development more rapidly than plants set out at a later date because of the increasing duration in photoperiod, increased temperatures, and the longer period of time of exposure to these environmental conditions. This early and prolific growth would unquestionably aid in the protection of the slope against erosion.

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